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USDA FOREST SERVICE RESEARCH NOTE

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OBSERVATIONS ON THE RHIZOMES AND ROOTS OF *VACCINIUM MEMBRANACEUM*

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by

Don Minore, *Plant Ecologist*

ABSTRACT

Rhizome occurrence and root structure of *Vaccinium membranaceum* were investigated by hydraulic excavation. Numerous, robust rhizomes were present. Taproots were not observed. *V. membranaceum* rhizomes sprouted vigorously after a light surface fire killed the shoots. They may be important in future huckleberry field management.

KEYWORDS: Huckleberry, *Vaccinium membranaceum*, root structure.

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

Vaccinium membranaceum Dougl. (thin-leaved huckleberry), the most frequently harvested *Vaccinium* species in western North America, grows at moderate to high elevations in the mountains of British Columbia, Washington, Oregon, Montana, and Idaho--usually in old burns. Its deliciously flavored fruits are gathered by thousands of berrypickers every year.

Unfortunately, most berry-producing areas are now reverting from old burns to poor quality subalpine forest. The wild huckleberry resource is dwindling rapidly (Minore 1972). If this important resource is to be preserved, tree invasion should be curtailed and the fields managed for berry production. However, berry field management is hindered by lack of information about the physiology, ecology, and anatomy of western huckleberries. Rhizome and root information is particularly scarce.

Rhizome information has been recorded for several *Vaccinium* species. The rhizomes of *V. angustifolium* Ait., the eastern lowbush blueberry, apparently contribute to its ability to survive burning at 2- to 3-year intervals--a practice commonly used to prune the bushes and increase yields in the managed blueberry fields of eastern North America (Barker et al. 1964, Black 1963, Chandler and Mason 1939, Trevett 1956). Lowbush blueberry plants also have deep taproots that may supply water and soil nutrients not available in the shallower soil occupied by rhizomes (Hall 1957). *Vaccinium* taproots have not been reported elsewhere. However, *V. pallidum* Ait. (dryland blueberry) spreads to form colonies much like those of lowbush blueberry (Darrow et al. 1944), indicating an extensive rhizome system in this southeastern United States species. Smith (1962) described the rhizome structure and distribution of *V. myrtilloides* Mich. (velvet-leaf blueberry) and *V. vitis-idaea* L. (mountain cranberry) in western Alberta. *V. myrtillus* L. (dwarf bilberry) develops a vigorous rhizome system in the British Isles (Ritchie 1956). Chemists in Oregon collected the roots and rhizomes of *V. parvifolium* Smith (red huckleberry) and thin-leaved huckleberry and analysed them for triterpene content, but made no morphological observations (Sheth et al. 1968).

The observations reported here were undertaken to investigate rhizome occurrence and general root structure in the thin-leaved huckleberry. Root systems of three huckleberry plants growing in coarse sandy soil near Mount Adams, Washington, were hydraulically excavated in September 1973. A gasoline-powered portable pump was used to force water from a nearby lake through a 4-cm-diameter hose and fire nozzle. The resulting water jet, applied progressively to an entire root system as the excavation proceeded, washed away the soil without damaging roots or rhizomes. Exposed root systems were photographed. The smallest system was diagramed by drawing each rhizome and root segment in place after distances between forks and depths below the soil surface were measured and recorded. Root and rhizome portions were taken to the laboratory, where they were sectioned, stained with Safranin O and Fast Green, and examined microscopically. Additional portions were examined after two more *V. membranaceum* plants were shovel-excavated near Mount Hood and on the Dead Indian Plateau east of Ashland, Oregon, in July 1975.

Numerous, robust rhizomes were present in every plant excavated. Ranging in diameter from 1 to 3 cm, most occurred 8-30 cm below the soil surface. Rootlike in external appearance (fig. 1), these rhizomes had numerous dormant vegetative buds. They revealed large central piths when viewed in cross section (fig. 2). Piths were not visible in cross sections of the roots (fig. 3). The smallest, simplest root system excavated is diagramed in figure 4. The largest

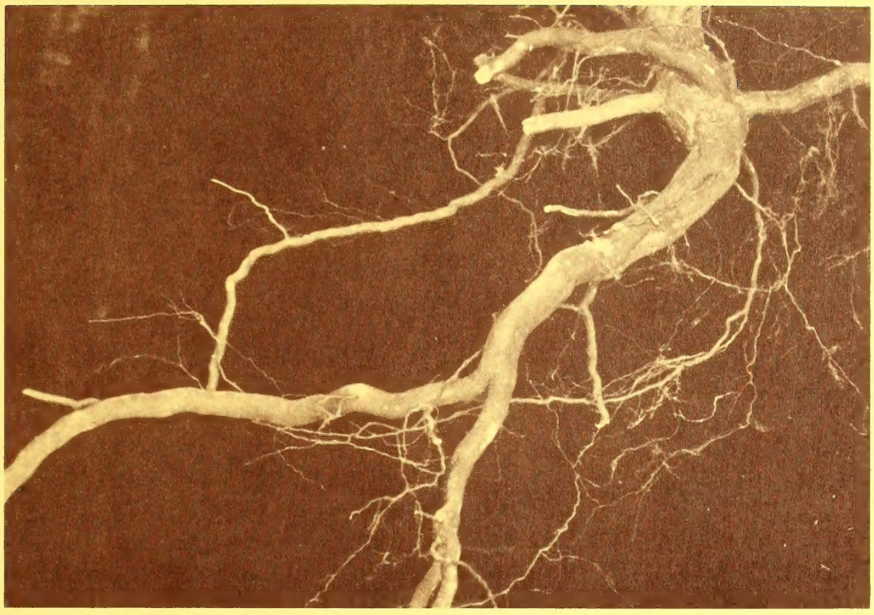

Figure 1.--Thin-leaved huckleberry rhizomes and roots viewed from above. The smaller, branching structures are roots. Small rhizomes are best differentiated from large roots by examining cross sections for presence or absence of pith.

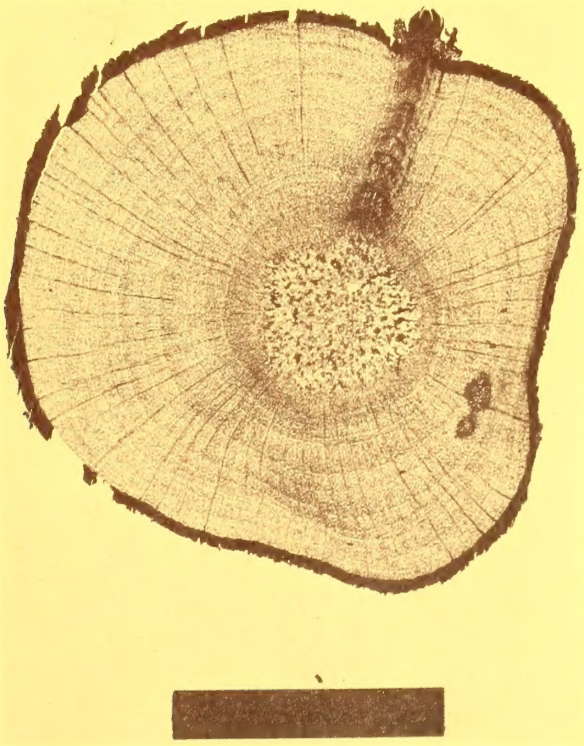

Figure 2.--Cross section of thin-leaved huckleberry rhizome. Note large pith and dormant bud. The bar is 5 mm long.

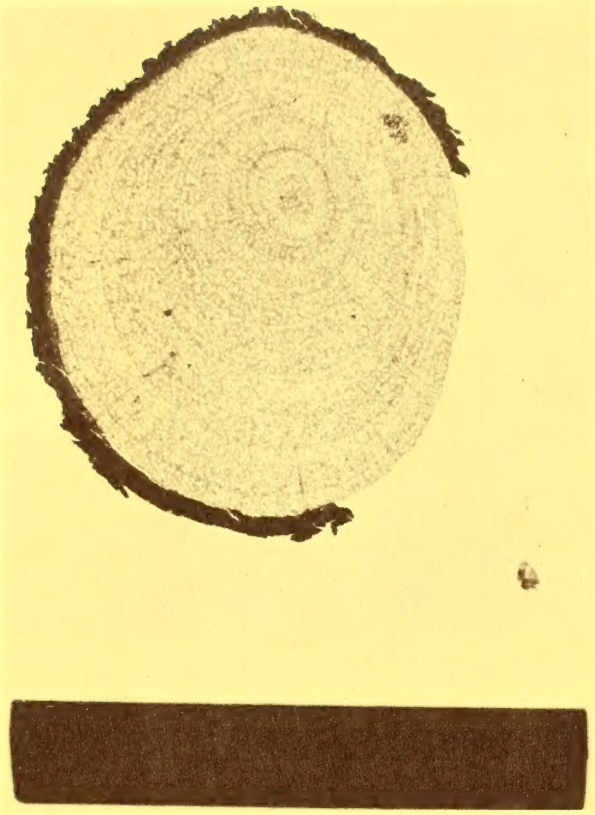

Figure 3.--Cross section of thin-leaved huckleberry root. Note the absence of pith. The bar is 5 mm long.

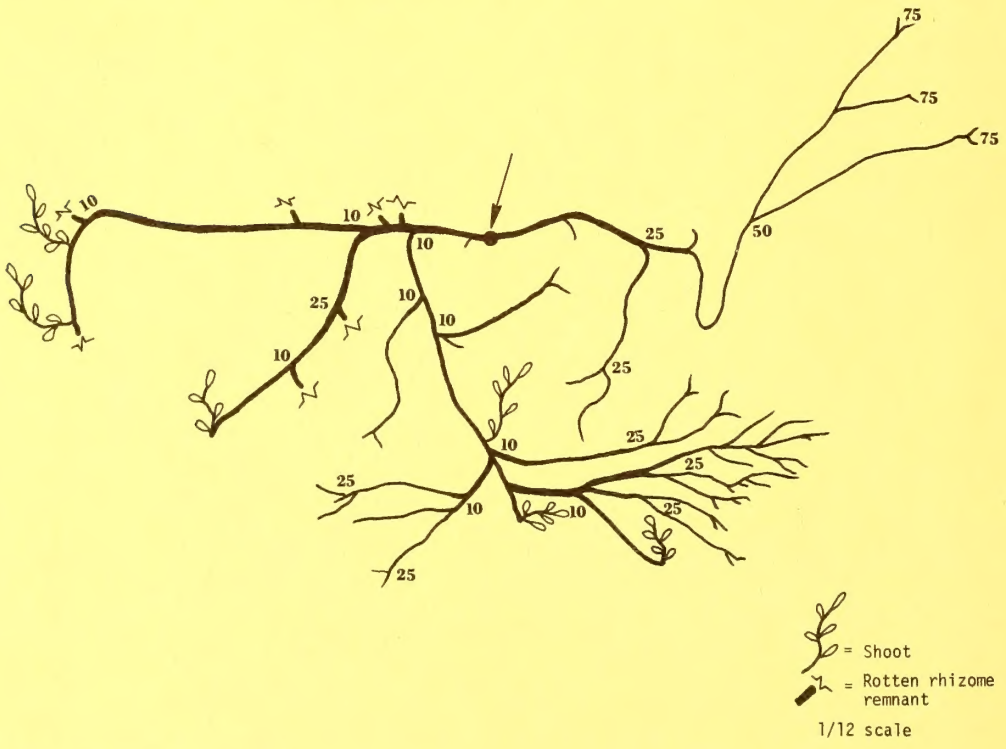

Figure 4.--Diagram of a simple rhizome and root system of thin-leaved huckleberry as viewed from above. Approximate depths (cm) are indicated. The arrow indicates probable origin of plant. Roots less than 5 mm in diameter are not shown.

root system occupied an area of 8 m^2. Supporting 47 shoots, it was a complex, multilayered maze that included hundreds of rhizome and root branches.

No taproots were observed in the excavated plants. However, occasional sinker roots were found descending to depths of 70-100 cm. Rhizome branching usually was dichotomous, but occasional burllike forks were encountered where three or more branches diverged at random angles from a common origin. Proximal and distal portions of the rhizome system usually were identifiable by fork orientation--where dichotomous branching occurred, the laterals diverged at angles of less than 90^o.

Neither rhizomes nor shoots were weighed, but rhizome and root biomass appeared to be much greater than that of the shoots. Most of the observed rhizomes were deep enough to avoid damage from light surface fires. Indeed, similar rhizomes sprouted prolifically after a 1972 fire. If the resulting shoots bear fruit in a reasonable period of time, it may be possible to enhance huckleberry vigor and control competing vegetation in thin-leaved huckleberry fields by burning them repeatedly.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

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MARKING METHODS FOR IMPROVING AERIAL APPLICATION OF FOREST PESTICIDES

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by

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ABSTRACT

Markers that are readily visible to the pilot are essential for proper identification of the boundaries of treatment areas and spacing of application swaths. They increase accuracy, efficiency, and safety of aerial application of pesticides and other materials.

Methods for placing marking panels in the treetops are described. The slingshot and crossbow methods are satisfactory for marking trees under 100 feet (30.48 m) in height. The line-throwing gun can be used for marking trees up to about 150 feet (45.72 m) tall and possibly taller, depending mainly on the load of power charges, ballistics of missile, weight of line, and firing angle. Helium-inflated balloons, protruding above the forest canopy, also are useful navigational aids. Other marking methods are also described and reviewed.

KEYWORDS: Pesticide application methods, spraying (aerial).

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INTRODUCTION

The accuracy, efficiency, and safety of such aerial applications as insecticides, herbicides, and fertilizers depend mainly on the aids available to the pilot for identifying boundaries of areas to receive treatments and gaging application swaths. Visible markers prevent accidental treatment of sensitive areas and minimize overdosage and underdosage caused by irregular spacing of swaths. The result is greater effectiveness of treatments and lower dosages.

The pilot must see at least two markers simultaneously for proper alinement of the aircraft path. Most agricultural ground markers would be impractical or unsatisfactory under forest conditions by being obscured by trees or topographic features and not visible from the air on oblique approaches.

Most information on methods of marking areas of forests for aerial application of pesticides is scattered, unpublished, and not readily available, either for field experiments or for operational use. There is a need to bring the information together so that the user can select the most desirable method for his specific needs.

The purpose of this paper is to describe some published and unpublished methods for placing colored markers in and above the treetops so that they are readily visible from the air under mountainous forest conditions.

LITERATURE REVIEW

Several methods have been used for placing markers on the trees from the ground. Eaton and others[1] marked corners of plots and midpoints of long boundaries to be sprayed with white wind socks or white canvas bags stuffed with brush and tied to the tops of trees. They did not mention how the wind socks and bags were placed on or above the trees. I assume that they were attached to long poles and placed in treetops by climbing the trees. Helium-inflated balloons, attached to high-speed reels, were used as swath markers. Some problems were encountered because the balloons were fragile, easily punctured, and difficult to carry through dense undergrowth.

Eaton et al. (1949) reported marking plot corners, where suitable openings occur, with large wooden or rock crosses on the ground. Also, trees, 100-140 feet (30.48-42.67 m) high, were marked with paint bombs and cloth streamers. A line-throwing gun was used to shoot a line over the tree to be marked. Aluminum paint bombs, containing detonator and dynamite, were hoisted by line and electrically detonated from the ground. The explosive force scattered the paint through the upper crowns. A similar method was used to hoist streamers into treetops.

Maksymiuk and others,[2] using the line-throwing principle, developed a simple and rapid method for placing colored plastic panels into treetops with the aid of a slingshot to mark boundaries of plots to be sprayed. Helium-inflated balloons, protected by light, plastic drycleaning bags, were effectively used to mark swath spacings.

Wickman[3] used a target long bow with a 29-inch (73.66-cm) arrows and

[1]C. B. Eaton, H. A. Jaynes, and J. M. Muiry. Experiments with airplane applications of DDT for spruce budworm control. Forest Insect Laboratory, Beltsville, Maryland. Progress Report, 26 p. 1949.

[2]Bohdan Maksymiuk, P. A. Boving, R. D. Orchard, and R. G. Winterfeld. Forest tests to develop an operational method to control the Douglas-fir tussock moth with a polyhedrosis virus. USDA Forest Service and Agricultural Research Service. Progress Report, 33 p. 1968.

[3]Boyd E. Wickman, Forestry Sciences Laboratory, Corvallis, Oregon, personal communication, 1975.

monofilament fishing line to place half muslin bedsheets on the treetops--40-70 feet (12.19-21.34 m) high--as markers for aerial photography. On the average, a two-man crew took 29 minutes to place marker with target bow in the treetop compared with 32.5 minutes by climbing. A target bow is underpowered for most field needs. The more powerful crossbow is better for marking taller trees--60-100 feet (18.29-30.48 m) high--and causes less fatigue than a target bow (USDA Forest Service 1974).

Collis and Harris (1973) used a .45-caliber line-throwing gun to hoist a cutter into trees for obtaining samples of branches. Hurtig and others[4] reported firing smoke-puff shells directly overhead which burst above treetop level, releasing brown smoke. This method, in combination with radio ground to air communication, enabled the pilot to line up accurately for each successive spray run.

Wear and Howard[5] described in detail two methods for marking the treetops from the air. The treetops were painted by the pilot or passenger from a hovering helicopter about 6 feet (1.83-m) above a tree and along one side of it. Fluorescent paint was sprayed from a pressurized tank using a 7-foot (2.13 m) long lightweight spray wand with a shutoff valve. A 2-foot(0.61-m) pipe with two spray nozzles was attached to the end of the wand.

The second method involved a crepe-paper streamer that spread into a treetop. It was thrown by hand from a helicopter flying at low speed--10-15 miles per hour (16.09-24.14 km/h). The marker consisted of four to six crepe-paper strips--5 inches by 5 feet (12.70 cm by 1.52 m)--attached about 8 inches (20.32 cm) apart along a 6-foot (1.83-m) string. A heavy metal washer was attached to each end of the string. The paper strips were accordion-folded into a 5- by 5-inch (12.70- by 12.70-cm) stack (fig. 1C). The marker was placed in the tree crown by holding one washer and crepe paper packet between thumb and forefinger, the other washer between the third and fourth finger, and throwing the packet assembly laterally at the treetop. R. D. Orchard (Aerial Applications Research Work Unit, Forestry Sciences Laboratory, Corvallis, Oregon) successfully used this method to mark trees from a helicopter. Impregnated cloth or plastic was satisfactory. Orange fluorescent streamers were more visible than other colors.

These two methods are especially suitable for marking trees rapidly in inaccessible large areas. However, these aerial methods may require previous ground identification of trees to be marked (or radio communication with ground crew) and are somewhat limited because of safety factors and displacement of marking materials by wind.

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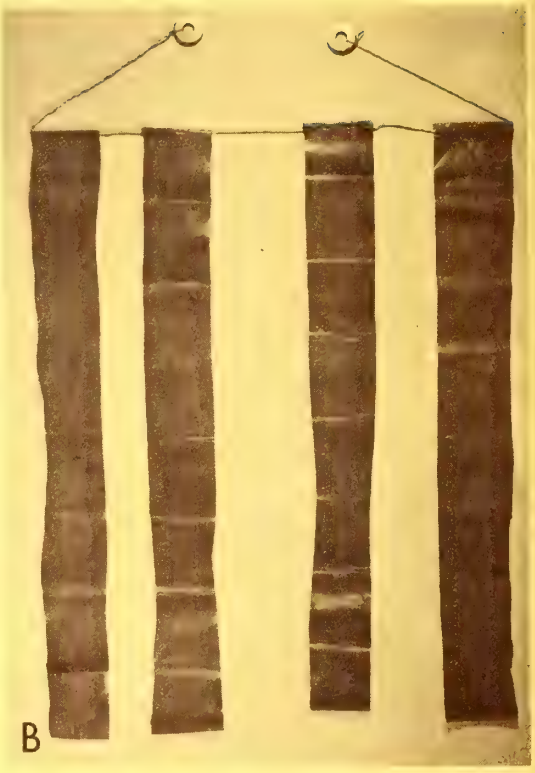
[4]H. Hurtig, J. J. Fettes, A. P. Randall, and W. W. Hopewell. A field investigation of the relation between the amount of DDT spray deposited, the physical properties of the spray and its toxicity to larvae of the spruce budworm. Defense Research Board, Department of National Defense, Canada, Suffield Experimental Station, Ralston, Alberta. Suffield Report No. 176, Part 6, 141 p. 1953.

[5]J. F. Wear and Benton Howard. New tree marking system improves forest spraying operation. Pacific Northwest Region, USDA Forest Service, Portland, Oregon. Unpublished report, 8 p. 1966.



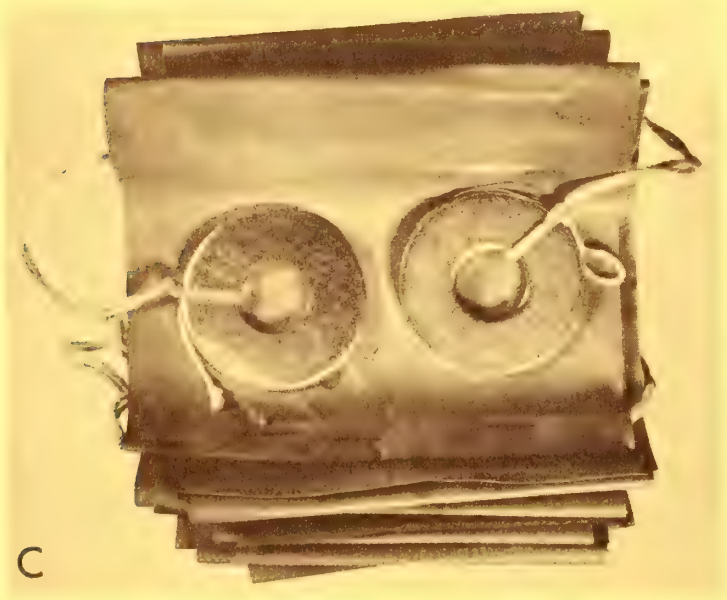


Figure 1.--Streamer assembly for marking trees from the air: A, Partially accordion-folded streamers attached to string with washers at other end of string; B, unfolded streamers; C, accordion-folded packet for field use.

PLACING MARKERS IN TREETOPS BY SLINGSHOT, CROSSBOW, AND LINE-THROWING GUN

General principle and procedures are similar for placing markers on the treetops by slingshot, crossbow, and line-throwing gun. Various methods and materials were investigated. Only tested materials showing satisfactory performance are given below.[6] The following materials are needed:

[6]Mention of products and companies by name does not constitute endorsement by the U.S. Department of Agriculture, nor does it imply approval of a product to the exclusion of others which may also be suitable.

1. Propellants

   (a) Wrist-Rocket® hunting and target slingshot (Wrist Rocket Mfg. Co., Inc., Columbus, Nebr.).

   (b) 80-lb (36.29-kg) thrust Power master® crossbow (Wham-O-Mfg. Co., Inc., San Gabriel, Calif.).

   (c) Marine E-Z Liner (line-throwing gun) with shoulder stock (Scientific Products Corp., 426 Swann Ave., Alexandria, Va.).

2. Projectiles

   (a) Fishing sinkers (elliptical and round) weighing 3-4 ounces (85-113 g), preferably sprayed with orange fluorescent paint to increase visibility.

   (b) Crossbow weighted bolts (a metal rod--3.5 by 0.25 inches (8.89 by 0.64 cm)--taped to the point of the bolt).

   (c) Soft plastic missiles, 5 by 3 inches (12.70 by 7.62 cm) (orange color), and hard metal missiles, 5 by 1 inches (12.70 by 2.54 cm) (orange color).

3. Line

   Nylon monofilament fishing lines--18- to 25-pound (8.17- to 11.34-kg) test--on spool for attaching projectiles to be fired.

4. Markers

   Light-reflecting yellow, white, and fire-orange plastic marking panels--18 by 60 inches (45.72 by 152.40 cm)--are cut from either 18 or 36 inches wide (45.72 or 91.44 cm), 300 feet long (91.44 m) rolls (Bergman Banner Co., 1822 Steiner St., San Francisco, Calif.). Holes are punched in two diagonally opposite corners of each panel with an eyelet punch and are reinforced with strong tape and brass eyelets. These holes are used for attachment of monofilament lines.

The slingshot and crossbow are available in most sporting good stores. The line-throwing gun with missiles can be obtained from marine dealers or directly from the manufacturer. The cost for the slingshot at time of purchase was under $5, crossbow under $60, and line-throwing gun under $160.

The basic steps for a two-man crew are:

1. Crewmember No. 1 attaches projectile (sinker for slingshot, bolt for crossbow, missile for the line-throwing gun) to the monofilament line (firing line) and catapults it over the treetop (fig. 2--A, B, C), letting the weight of the projectile pull the line down.

2. Crewmember No. 2 removes the projectile, ties the firing line firmly to one corner of the marking panel (fig. 2D) through the reinforced hole in the panel, and ties a second monofilament line (guide line) in the same way to the diagonally opposite corner of the panel.

3. Crewmember No. 1 hoists the marker onto the treetop by pulling on the firing line, and crewmember No. 2 assists in positioning the marker on the treetops (fig. 2E) by using the guide line. Crewmen cut both lines and tie them to the trees high enough to prevent accidental dislocation by animals. Colored flagging is attached to the lines for ease in locating them later. After aerial application, marking panels can be removed for reuse by cutting one line and pulling the second line.

Observations

Recently, R. D. Orchard, M. J. Haskett, and Drs. John Neisess and G. P. Markin of the research work unit on aerial application and others used slingshot, crossbow, and line-throwing methods for marking trees for aerial application of insecticides. Personal preference for a particular method varied. In general, the following can be concluded:

Figure 2.--Marking trees from the ground: Projectiles (sinker, bolt, missile) attached to the monofilament line are catapulted over the treetop with the slingshot (A), crossbow (B), and line-throwing gun (C); projectile is removed and the line attached to the marking panel (D); hoisted panel is shown in treetop (E); a pair of captive helium-inflated balloons (F) can be seen above the treetops (in shadow of the helicopter).

1. Slingshot method is preferable for marking trees under 60 feet (18.29 m) tall; however, this method can be used for placing markers on trees up to 100 feet (30.48 m) in height. Sinkers sprayed with an orange fluorescent paint or tagged with a ribbon (see fig. 2A, arrow) helped to located the end of the line after it had been shot over the tree.

2. Crossbow method is satisfactory for placing markers on the intermediate trees--60-100 feet (18.29-30.48 m) high. A metal rod--3.5 by 0.25 inches (8.89 by 0.64 cm)--taped to the point of the bolt provided enough weight--about 2 ounces (57 g)--to pull the line to the ground.

3. Line-throwing gun method is suitable for placing markers on trees up to 150 feet (45.72 m) or taller, depending on the type of missile used (large plastic or small metal), the load of the power charges, weight of the line, firing angle, and wind resistance.

4. Both the line-throwing gun and crossbow methods have disadvantages compared with the slingshot method for marking short trees because of the excessive power (bolts and missiles overshoot treetops). This can be remedied sometimes by shooting bolts or missiles from a steep slope, if available, well below the tree to be marked. During high wind, the crossbow bolt should be shot upwind into the top of the tree to be marked.

5. Marking panels should be placed in the treetops, by the line-throwing method, only a few days before aerial application. This will reduce the chance of markers sliding down from the treetops. All markers should be checked the day before spraying and pulled back to the treetops if loose or displaced. If marker is on one side of the tree and cannot be readily visible to the pilot, a second marker can be placed on the other side of the same tree. Orange and red panels were more visible than other colors.

Caution. The slingshot, crossbow, and line-throwing gun can be dangerous if used carelessly. Detailed instructions for operation, maintenance, and safety are provided by the manufacturers. All equipment should be inspected for proper and safe functioning. Shooting range should be clear of people. Pulling the line to retrieve projectiles stuck in the tree branches is dangerous; instead, the line should be cut and the projectile will usually drop to the ground in the predetermined spot.

PLACING HELIUM-INFLATED BALLOONS AND PANELS ABOVE THE TREETOPS

Helium-inflated balloons and panels can be used for marking boundaries of spray areas and swaths.

Captive balloon method.--The following materials are needed:

1. Balloons. Brightly colored balloons were purchased in novelty stores. Stronger and larger meteorological balloons, weighing 0.70 ounce (20 g), were also used (Weather Measure Corp., P.O. Box 41257, Sacramento, Calif.).

2. Helium. Portable helium cylinders with the regulator valve.

3. Line. Lightweight string or monofilament line, 5- to 8-pound (2.27- to 3.63-kg) test, wound on spools.

4. Bags. Lightweight plastic dry-cleaning garment bags.

5. Weights. Heavy fishing sinkers, 10 to 20 ounces (283 to 567 g).

6. Reel. Commercial or homemade reel or spool for storing line.

The following procedure is used:

1. Inflate balloons with helium, tie with a string, attach line, and test for leaks and lift capability. If the lift is insufficient, use more helium or a lighter line, or preferably use two balloons in tandem attached to one line. Slip lightweight plastic drycleaning bag over balloons.
2. Release balloons until they are above the treetops and fasten the line to heavy sinker or other object on the ground. Balloons can also be used to indicate desired height for spraying at low wind velocities (fig. 2F).

Pulling balloons down after each swath run prevents accidental retreatment of the same area (see footnote 2). This captive balloon method was satisfactory for temporary markers for spray swaths in conjunction with the panel markers on the treetops indicating plot boundaries. Balloons should be kept away from sharp objects, sun, and oil sprays; I recommend two balloons inside a lightweight plastic drycleaning bag for increasing the lift and lifespan of the balloons. They should be inflated and placed in the bags shortly before aerial application

Elevated-pole and flag method.--The following materials are needed:

1. Panels. Colored plastic or cloth panels or streamers can be used.
2. Poles. Long, lightweight poles (single, multiple, or telescoping).

The following procedure is used:

1. Attach flag, panel, or streamer firmly to the end of pole.
2. Climb the tree and pull up the pole by rope.
3. Elevate pole with marker above the treetop to the desired height and tie it with a rope to the tree.
4. Climb down and inspect the marker.

Elevated-pole and flag method is especially satisfactory for marking trees that can be climbed safely. Advantage of this method is that trees can be marked well in advance of aerial application. Markers are not displaced by wind.

OTHER METHODS

Below are several marking methods that offer some potential.

Smoke

Smoke-generating devices mounted on spray or guide aircraft can be used especially for marking swaths for treatment in large and inaccessible forest areas. Ground smoke-generating devices (smoke bombs, Ben Meadows Co., 553 Amsterdam Ave., N.E., Atlanta, Ga.) can be used in large forest openings. These methods are simple; however, smoke behavior and displacement can be adversely affected by airmass movement.

Flares

Aerial signal cartridges (SFR-2) ejected by a small pengun (Penguin Industries, Inc., P.O. Box 98, Parkersburg, Pa.; Ben Meadows Co.) can be used as temporary or emergency markers in areas where there is little fire hazard (swamps, lakes). According to the manufacturers, flare can ascend to about 350 feet (106.7 m) and burn with a brilliant red light of about 12,000 candlepower for 6-9 seconds. Other colors are available.

Special Balloons

Helium-inflated large balloons, such as Kytoon® (W. R. Grace & Co., 62 Whittmore Ave., Cambridge, Mass.) can be useful navigational markers in open terrain. However, their use as markers in forestry is limited because of the large amount of helium needed, maneuverability, and high cost.

Moving Flagman

This method can be used satisfactorily for indicating swath spacings during aerial applications in the open forest or on rangeland. This method usually involves one person on each side of application plot, holding a flag on a handle. Both flagmen move a predetermined distance (swath width) and signal the pilot. Flagmen should avoid inhaling pesticides and exposure to descending pesticides by staying upwind and wearing protective devices and clothing.

Automatic Flagman

An automatic flagman, a pilot-operated aircraft tagging system (Air-Ag., Inc., Route 4, City-County Airport, Walla Walla, Wash.) offers promise for certain forest and rangeland applications. Weighted paper streamers are ejected from the dispenser mounted on either fixed- or rotary-wing aircraft. During the spraying of sagebrush, it was found that the automatic flagman could not replace a moving flagman because many markers fell between clumps of brush and were not readily visible to the pilot (USDA Forest Service 1969). A similar situation was observed under forest conditions by Drs. G. P. Markin and John Neisess (Forestry Sciences Laboratory, Corvallis, Oreg.).

Placing colored markers in the openings on the ground or on the top of vegetation is a satisfactory method of indicating where herbicide should be applied for release of small conifers from dense brush.[7]

Electronic Aids

Aircraft equipped with electronic aids, such as a Decca Navigator System, offer potential for large aircraft treating extensive, flat areas (Underwood 1971, International Agricultural Aviation Centre 1973). However, these developments in avionics have not yet found practical application in forestry in the United States because of cost and complexity of the equipment and treatment of the small, mountainous areas common in forestry.

CONCLUSIONS

User can select any method (or combination of methods) or modify it according to his specific field needs. The described marking methods proved satisfactory during aerial applications of insecticides under variable forest conditions. They can also be used for some aerial applications of herbicides and fertilizers.

The slingshot and crossbow methods are satisfactory for marking trees under 100 feet (30.48 m) in height. The line-throwing gun can be used for marking trees up to 150 feet (45.72 m) or taller, depending on the load of power charges, firing angle, weights of projectile and monofilament line, and other factors. Light-reflective plastic marking panels were superior to cloth panels due to visibility and no snagging problems in pulling them through the crowns into the treetops. They were visible for at least 1 mile. Orange, yellow, and red markers were preferred to other colors by the pilots. An average of about 20 minutes, with a two-man crew, was necessary for placing marker into treetop with slingshot, crossbow, or line-throwing gun.

Captive helium-inflated balloons and elevated poles and flags protruding above the forest canopy can be useful navigational aids. Well-identified boundaries of areas for treatment and swath spacings can result in more productive flying time, less fatigue to pilots, safety, and more accurate and efficient aerial application of pesticides.

[7]Dr. R. E. Stewart, Forestry Sciences Laboratory, Corvallis, Oregon, personal communication, 1975.

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USDA FOREST SERVICE RESEARCH NOTE

79 PNW-263

PNW-263 November 1975

PROTECTING EXPOSED ENDS OF TIMBER BEAMS IN THE PUGET SOUND AREA

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by

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Forest Products Technologist

ABSTRACT

When heavy timber members are fully exposed to the weather, changes in moisture content caused by the action of sun and rain are appreciable. This exposure is most severe on end-grain surfaces which absorb moisture rapidly. Stresses in beams of large sections usually cause checking, staining, and degradation of finishes. In the rainy climate of the Puget Sound area, moisture contents in the wood readily reach levels at which decay occurs, and even pressure-treated timbers may decay if deep checks allow water to penetrate to untreated material in the interior.

Finishes, flashings, and protective covers may be used to reduce these effects; and experimental evaluations of many potential protective methods are needed to identify systems which provide satisfactory durability and minimize maintenance. This report describes weather exposure tests of 12 protective methods, with observations of moisture content and appearance over a 3-year period. One finishing system and two types of protective covers appear to provide adequate protection.

KEYWORDS: Moisture barriers (wood), wood as building material, finishes (wood).

INTRODUCTION

When heavy timber beams extend outside a building to support an overhang or are used in open structures such as walkways, they are usually protected from the elements by the overhang. A fascia board may be used to provide partial cover at the ends, and the lower portion may be cut back at an angle to avoid direct exposure to sun and rain (fig. 1).

Figure 1.--Tapering of overhang exposes minimum end section.

These measures are usually adequate to limit exposure of the vulnerable ends so that extreme weathering effects do not occur. However, in many cases, designers prefer to extend the square end of a beam to the fascia or even well beyond the overhang protection. This may be done to support sunshades or other functional framing or simply to emphasize the massive ends of large sections.

This practice presents a severe weathering problem, frequently resulting in early damage to the wood and to applied finishes. Clear coatings deteriorate rapidly in direct sunlight, and no commercially available clear coating is fully effective in preventing moisture change in the wood. Moisture changes cause appreciable dimensional changes in large timber sections, usually resulting in considerable checking on ends and top surfaces. These checks, in turn, admit more water, sometimes causing blistering and flaking of the finish and a badly stained and discolored surface (fig. 2). In addition, the wood is weakened by excessive moisture which may reach levels at which decay occurs. Decay frequently occurs in warm, moist climates; and irreparable damage may result. Severe exposures require protective systems which need little or no maintenance, since access may be difficult or costly.

Figure 2.--Decay in an exposed beam end in the Northwest.

Finishes

Problems attending the complete exposure of heavy timbers may be minimized by application of one of a variety of finishes and coatings. Unfortunately, those transparent enough to show the wood grain are less effective in retarding moisture changes and less durable under solar exposure. Frequent refinishing is required to maintain transparent finishes, and surface coatings such as varnish often must be completely removed before satisfactory refinishing can be achieved. Recent practice has favored use of penetrating stains which can be readily refinished without removal. These may contain a preservative and a moisture repellant, and their durability varies with the type and amount of pigment included, the porosity of the wood, and the number of successive applications. However, stains, whether semitransparent or solid color, oil-base or latex-base, are not effective in excluding moisture vapor.

Opaque coatings such as paint can be colorful and attractive, even though they conceal the natural wood grain. Solvent-thinned coatings of good quality, when applied in two or three coats over a suitable primer, are durable coatings with good resistance to moisture, both liquid and vapor. Maintenance may not be required for from 5 to 10 years, depending on location and orientation. Some of the better quality water-thinned paints (latex paints such as the acrylics and vinyl-acrylics) may be even more durable than the better solvent-thinned paints, but they form open or porous films. Consequently, they are not effective in excluding water and moisture vapor from wood.

Finishes are primarily decorative, however, and the protection they provide to heavy timber sections is limited in degree and time. They require maintenance

to continue their protective function; and maintenance is frequently inadequate, inexpert, or nonexistent.

Flashings

Durable, waterproof covers or flashings can be provided at beam ends to exclude rainwater from the absorbent end-grain surfaces and to protect top surfaces. Such covers also reflect solar heat, greatly reducing moisture content changes and protecting applied finishes.

One type frequently used is a conventional metal flashing, custom formed to cover top and end surfaces. Metal covers may be simple and functional, painted to blend with the wood, or they may be used as decorative accents in a wide variety of shapes and natural metal colors, from bright stainless steel to the dull gray of zinc-titanium alloys, the many anodized colors of aluminum, and copper and brass (fig. 3). Decorative accents in metal are hardly new in architecture; they were frequently used in the temples of the Far East before the time of Christ, lending charm as well as cover.

Figure 3.--Decorative metal end cap.

Thoughtfully designed metal flashings can be effective in excluding water and reducing the effects of solar heat, but some existing flashings are inefficient or self-defeating. It is essential that flashings cover the top as well as the ends of a projecting member and be well lapped or counterflashed where the top edge of the beam intersects the roof or wall. An adequate drip-edge should be provided to shed water from the top away from side surfaces, and a drip-edge at the end should extend well below the bottom surface to prevent windblown rain from feeding into end grain at the bottom. It is believed desirable to set the entire flashing on blocking to provide a ventilating airspace between beam and flashing, allowing the wood to "breathe" and avoiding direct contact with condensation which may form on the metal under some conditions. A completely airtight sleeve covering side and bottom surfaces of the beam should be avoided, since this would serve to contain any moisture already in the beam as well as conceal any damaging effects.

Wood cover plates are simple and attractive alternatives to metal flashings

but present another set of practical difficulties. Where thin boards are used, warping is common, causing a crack to open at one or more edges where water can enter and be contained by capillarity. Because the boards are usually short, splits develop easily either after stress from the fasteners or by deformation due to moisture changes. Thin plywood plates are a better choice, since the tendency to split is eliminated and a better balance of grain reduces the tendency to split is eliminated and a better balance of grain reduces the tendency to warp or cup. Cupping is not eliminated in plywood exposed to the weather, however, and there is still a need for firm attachment to restrain any imbalance and prevent the opening of edge cracks. Nailing a plywood plate into the end grain of the beam is no solution, as it leaves a crack all around the edge which will almost certainly enlarge in time.

As with metal flashings, plywood plates must cover any exposed top surface of the beam as well as the end-grain (fig. 4). This reduces checking on the top surface and keeps water out of any checks which occur, but it also provides an opportunity to cover the joint at the end plate and provide a drip-edge all around.

Figure 4.--Plywood plates furnish cover and shade for the beam.

The best method of attaching the plywood plates appears to be a waterproof adhesive. Although many adhesives are unsuitable for field application or for use on relatively coarse end-grain surfaces, the recent development of elastomeric construction adhesives provides a simple method of application with an easily obtainable material with promising characteristics. Elastomeric adhesives are now available in cartridges for convenient application in the field, and they can be uniformly spread with a notched linoleum trowel. They can be applied over a wide range of temperatures.

Other possible coverings include many of the durable plastic or composite sheets, provided they can be adequately formed or joined. Durable plastic coating systems, with or without reinforcing, are now available as waterproof membranes for roofing and waterproofing. These membranes can be made to conform to any shape and are available in a range of colors. Membrane systems based on Neoprene, Hypalon, Silicone, and vinyl are among those commercially available. A deterrent

to their use might be the specialized application involved, but on new work the roofing contractor usually could include such flashings in his contract, as well as metal flashings.

Previous Research

The U.S. Forest Products Laboratory, Madison, Wisconsin, has long been active in the evaluation and development of finishes for wood. Recent exposure tests of paint systems applied to laminated beam sections at Olympia, Washington, confirm the durability of several commercially available paints over 8 years. These systems, consisting of combinations of aluminum or other zinc-free primers with two top coats of either titanium-lead and oil or acrylic emulsion paint, effectively protected the samples over the test period. Checking in the samples was minor, and little deterioration of the finishes was observed. It should be noted, however, that these laminated samples were relatively small in section, about 6 by 7 inches. Much larger laminated sections are now in common use, and the magnitude of dimensional changes increases with the size of the section. Thus, these tests do not adequately predict the performance of paints on much larger sections, where small changes in moisture content cause relatively larger changes in dimensions which may rupture the coating.

CURRENT TESTS

To extend our knowledge of finishes on larger sections and to evaluate several types of flashings, the Environmental Wood Use project in Seattle has initiated a comparative study at its exposure site near Olympia, Washington. A total of 24 glulam Douglas-fir blocks 6-3/4 by 18 by 29 inches long, bonded with waterproof adhesive, were obtained from an American Institute of Timber Construction qualified laminator. Laminations were standard 2-inch nominal thickness, as normally used in straight members, and grain direction was random. Each block was moisture-sealed at one end with hot asphalt, so only the opposite end and side surfaces could absorb moisture, simulating the exposed end of a longer laminated beam. A moisture sensor[1/] was placed 3 inches from the unsealed end at approximately the midheight of the section, and a thermocouple was placed near the sensor in a control sample to measure the temperature within the wood when moisture content readings were made. Each pair of blocks consisted of laminations from separate lumber layups to assure that grain characteristics were not similar in the two blocks, and each pair was treated with a coating, paint system, or flashing. In November 1971, eight pairs of samples were prepared under cover and set out on racks at the exposure site; and in November 1972, four additional pairs were prepared and placed, for a total of 12 pairs of blocks, each pair having a different treatment, as indicated in table 1. Moisture contents of the samples at the time of placement varied from 7 to 9 percent. Figure 5 shows how the 24 samples were placed on a continuous rack horizontally and about 24 inches above the ground, with the treated end facing south.

Figures 6 and 7 show details used for all plywood covers and for the metal cap flashings.

[1/] J. E. Duff. A probe for accurate determination of moisture content of wood products in use. USDA Forest Service Research Note FPL-0142, 10 p., illus. 1966.

Table 1--*Protective methods used on samples*

Sample	Type	Sealer or primer	Finish or flashing
1A 1B	Controls-- stain	Water-repellent penta, all surfaces	One coat semitransparent acrylic stain
2A 2B	Acrylic paint	Water-repellent penta, plus acrylic primer	Two coats brown acrylic paint
3A 3B	3/8-inch plywood Neoprene	Water-repellent penta, side surfaces only	3/8-inch unfinished redwood plywood covers, top and end, Neoprene bonded
4A 4B	Timberlab varnish	Water-repellent penta, all surfaces	Three coats Timberlab British Experimental Varnish
5A 5B	Polyurea paint	One coat resin sealer, all surfaces	Two coats white resin paint
6A 6B	Vinyl with glass fiber	One coat vinyl primer on flashing area	One layer 16-mesh glass fiber cloth; two coats vinyl resin over fabric
7A 7B	3/8-inch plywood Silicone	Water-repellent penta, side surfaces only	3/8-inch unfinished redwood plywood covers top and end, Silicone bonded
8A 8B	Metal flashing	Water-repellent penta, all surfaces	One coat acrylic stain, all surfaces; zinc-titanium alloy flashing
9A 9B	Acrylic varnish	One coat clear acrylic sealer, all surfaces	Two coats clear acrylic varnish
10A 10B	Neoprene coating	Water-repellent penta, side surfaces only	Elastomeric Neoprene adhesive, troweled on top and end surfaces
11A 11B	1/2-inch plywood Neoprene	Water-repellent penta, side surfaces only	1/2-inch stained Douglas-fir plywood covers, top and end, Neoprene bonded
12A 12B	1/2-inch plywood Silicone	Water-repellent penta, side surfaces only	1/2-inch stained Douglas-fir plywood covers, top and end, Silicone bonded

Figure 5.--Partial view of samples on rack, showing asphalt sealed ends.

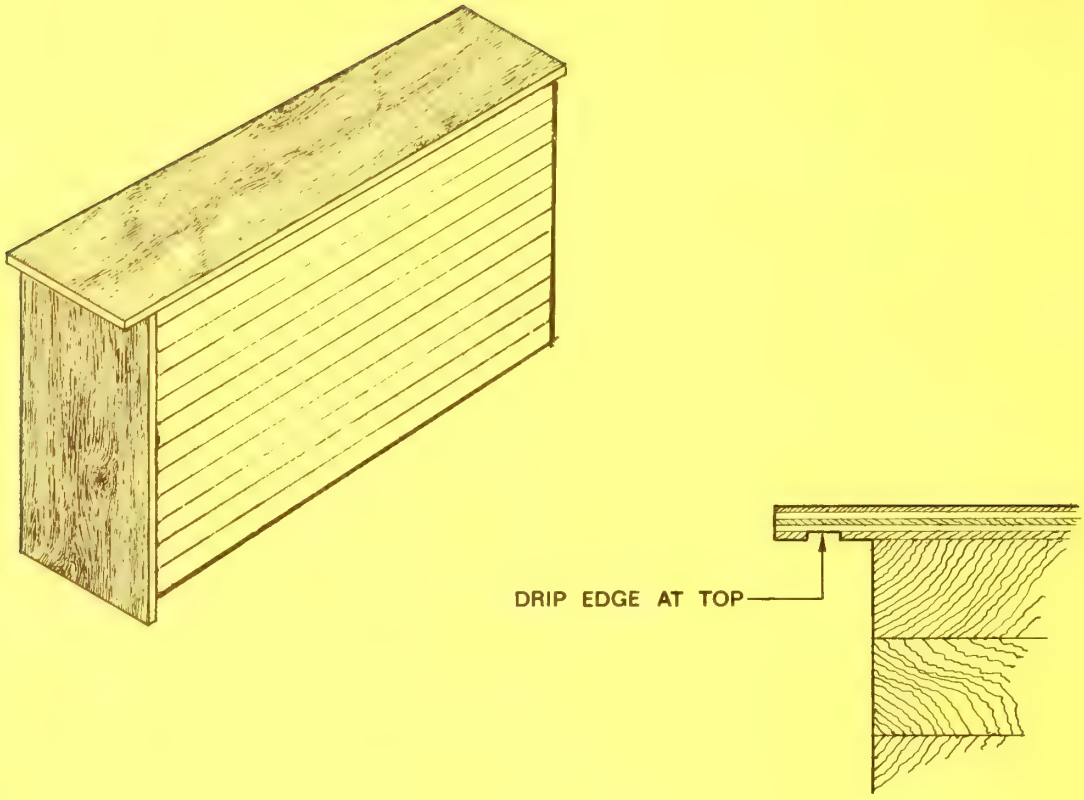

Figure 6.--Plywood covers.

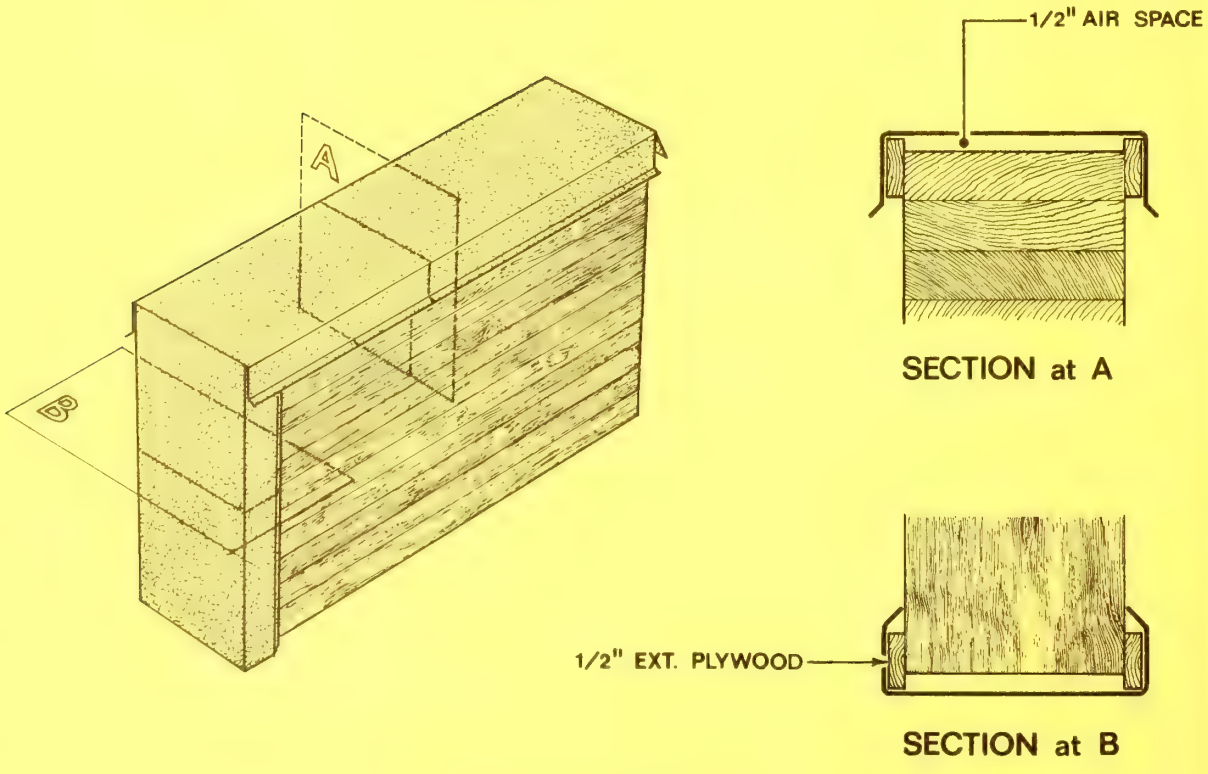

Figure 7.--Metal caps.

OBSERVATIONS AND DISCUSSION

Samples were examined on a monthly or bimonthly basis the first year, but this frequency was found to be unnecessary and the interval was extended to semiannually the second year and reduced again to approximately quarterly the third year. During each observation, moisture contents of all samples were recorded (table 2), and photographs were taken of any significant changes in appearance. Readings omitted from the table on samples 1B and 6B result from an initially insufficient supply of moisture sensors. Other omissions indicate readings that appeared erratic by the action of the meter or were believed influenced by local moisture concentrations.

The effects of weathering on an inadequately protected beam end may be seen in figures 8, 9, and 10, where the considerable stresses occurring are clearly evident in the progression of checks and splits in the surfaces over a short period of time. These are the control samples, finished with light pigmentation and were expected to deteriorate rapidly. In terms of appearance and moisture content, failure may be said to have occurred in 4 months, with continued subsequent deterioration over the next 18 months.

The acrylic paint samples, 2A and 2B (table 1), performed only a little better, with some end checking appearing after 4 months and large top and side checks developing in 5 more months.

This paint system probably would have performed better if a more effective vapor barrier, such as several coats of aluminum paint, had been substituted for the acrylic primer.

Table 2--*Percent moisture content of beam samples*[1/]

Sample	Treatment	Reading date														
		Feb. 1972	Mar. 1972	Apr. 1972	June 1972	Aug. 1972	Sept. 1972	Nov. 1972	Apr. 1973	June 1973	Aug. 1973	Nov. 1973	Mar. 1974	June 1974	Sept. 1974	Mar. 1975
1A	Controls--	18	24	19	16	12	11	11	--	17	--	30	30	35	9	35
1B	stain	--	--	--	--	--	--	--	--	25	--	45	65	65	13	50
2A	Acrylic	17	17	17	13	11	11	11	--	20	--	22	40	40	13	25
2B	paint	9	11	10	10	9	9	9	--	11	--	12	22	19	10	19
3A	3/8-inch plywood	18	19	19	15	8	6	7	--	9	--	8	11	14	10	8
3B	Neoprene	45	40	25	8	7	7	7	--	8	--	30	30	30	30	19
4A	Timberlab	25	25	22	30	30	35	22	--	12	--	8	--	--	6	12
4B	varnish	8	10	8	9	7	6	19	--	9	--	23	23	10	7	19
5A	Polyurea	8	10	7	8	8	8	7	--	9	--	9	9	9	9	--
5B	paint	8	14	8	8	8	9	8	--	9	--	10	10	10	10	11
6A	Vinyl with	8	10	10	12	11	12	11	--	14	--	13	15	16	15	18
6B	glass fiber	--	--	--	--	--	--	--	--	16	--	45	9	--	7	8
7A	3/8-inch plywood	10	12	12	12	11	11	11	--	13	--	12	13	14	11	13
7B	Silicone	10	13	12	13	12	12	12	--	10	--	12	14	15	11	14
8A	Metal	12	13	12	11	9	8	10	--	10	--	10	11	10	7	11
8B	flashing	13	19	17	13	9	8	12	--	12	--	17	25	10	7	13
9A	Acrylic	--	--	--	--	--	--	--	10	12	10	40	40	16	6	11
9B	varnish	--	--	--	--	--	--	--	11	14	10	40	30	19	13	30
10A	Neoprene	--	--	--	--	--	--	--	13	14	12	40	30	21	11	25
10B	coating	--	--	--	--	--	--	--	13	15	15	55	40	40	14	35
11A	1/2-inch plywood	--	--	--	--	--	--	--	19	15	12	12	14	14	11	14
11B	Neoprene	--	--	--	--	--	--	--	12	14	12	11	14	15	11	15
12A	1/2-inch plywood	--	--	--	--	--	--	--	23	17	13	13	16	16	12	15
12B	Silicone	--	--	--	--	--	--	--	13	13	12	21	13	14	7	8

[1/] Readings below 25 percent have been rounded to the nearest whole number; 25 percent and above, to nearest 5 percent. Readings omitted on samples 1B and 6B result from an initially insufficient supply of moisture sensors; other omissions indicate readings that appeared erratic by the action of the meter or were believed influenced by local moisture concentrations.

Figure 8.--End checking in 1B after 4 months.

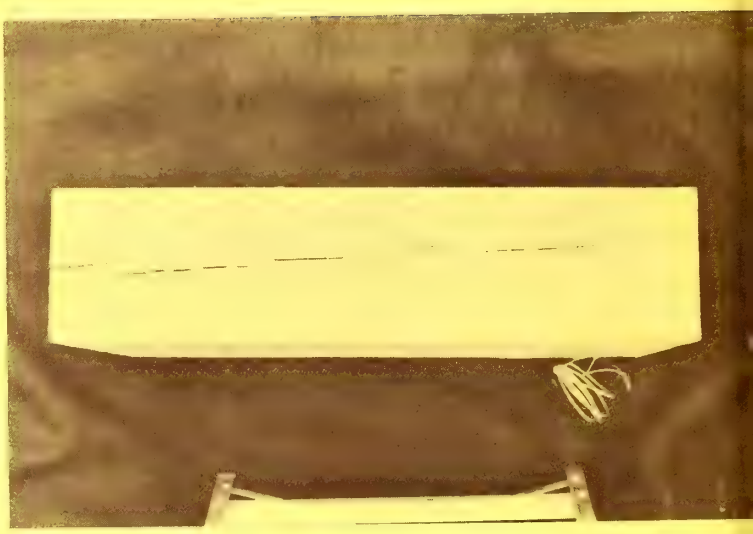

Figure 9.--Checks in top of 1A after 9 months.

Figure 10.--Deep split in east side of 1B in less than 2 years.

The varnish systems, samples 4A and 4B and 9A and 9B, quickly showed evidence of failure also. The Timberlab varnish (4A and 4B), an experimental varnish developed by a British Government laboratory, showed slight end checking in 3 months, with water-staining appearing under the varnish near edges in another 6 months, a completely unsatisfactory appearance and unsatisfactory protective coating resulting within the first year (fig. 11). This varnish was designed to screen out the

Figure 11.--Water staining under varnish at top of 4B after 9 months.

ultraviolet rays of the sun and extend the coating's life, but failure occurred because water seeped under the varnish at the sharp edges where the coating was thin. The same mode of failure developed in an equal time in the clear acrylic varnish (9A and 9B), but an interesting difference appears on the end grain surfaces, where the good end-sealing qualities of this varnish prevented any end checking during the entire 2-year exposure (figs. 12 and 13).

Figure 12.--Water staining under varnish in 9A after about 16 months.

Figure 13.--Good moisture sealing at end prevented checking in 9A.

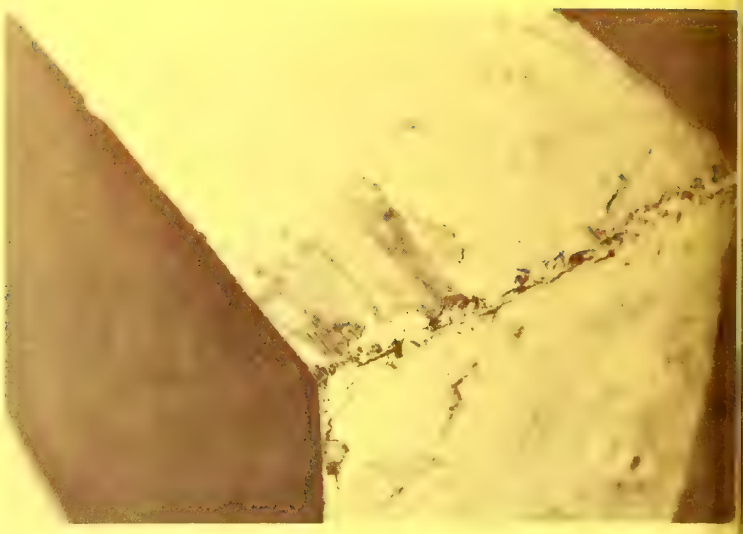

Figure 14.--Peeling of coating in 10A.

The troweled-on Neoprene coating (10A and 10B), lasted about a year before becoming brittle and cracked, allowing water to penetrate beneath it. It then began to lose its adhesion and peeled (fig. 14).

The only coating system to give outstanding promise of long life and virtuall complete protection against water was the polyurea paint system (5A and 5B). Afte exposure for 3 years, there was no observable deterioration of this finish, and moisture contents in the wood remained very low through both wet and dry seasons (fig. 15).

Figure 15.--Excellent appearance of 5A and 5B after 3 years.

The vinyl-based plastic flashing, reinforced with glass fiber (6A and 6B), appeared to be keeping the wood dry for about 6 months, but after this time some checking on side surfaces developed. After 3 more months, a large check developed in the side of sample 6B; and in another year, it became split along its entire length, tearing through both the flashing and the asphalt seal on the back (fig. 16). At the end of 34 months, tears also appeared at the end of sample 6A (fig. 17), suggesting that a tightly adhered flashing of this kind may not be an adequate solution for large beam sections.

Figure 16.--Deep split in west side of 6B ruptures flashing.

Figure 17.--Splitting of flashing at end of 6A.

The plywood covers in samples 3A and 3B, 7A and 7B, 11A and 11B, and 12A and 12B retained their integrity through the entire period of exposure, though the 3/8-inch unfinished redwood plywood on the first two sets of samples had some surface deterioration due to checking and some peeling of flat grain. The sample blocks swelled with moisture more than the plywood on the ends, so that a small crack opened at the top, under the top cover. This was protected, however, by the overhang of the top cover and probably had little effect. In sample 3B, some warping of the end cover also occurred, perhaps admitting wind-driven rain at the vertical edges. Although samples 3A and 3B had variable high moisture contents, all other plywood samples performed well in limiting moisture contents to low levels. Generally, this method of flashing may be recommended when it is carefully installed, but the better dimensional balance and resistance to warping of the five-ply 1/2-inch plywood suggest its superiority for this use (fig. 18). The plywood should also be finished for its protection, usually in the same manner as the beams.

The metal flashings (fig. 19) used on samples 8A and 8B also appear to have performed well in limiting high moisture contents, though several readings

Figure 18.--Plywood covers on 7A and 7B.

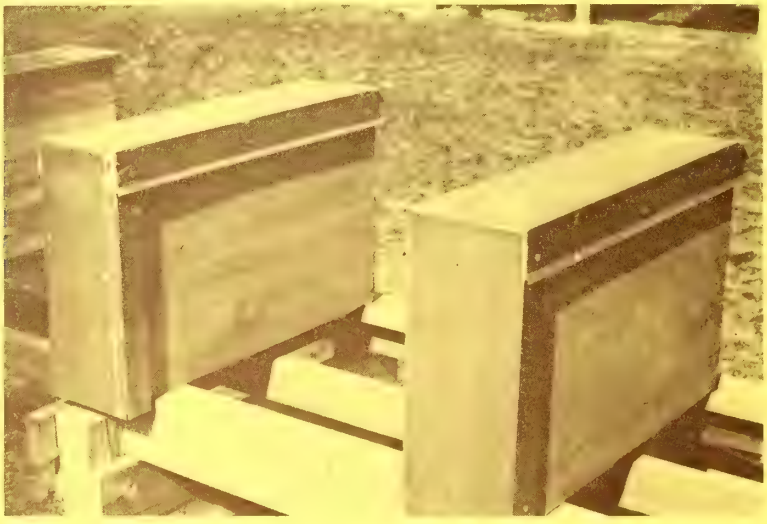

Figure 19.--Metal flashings on 8A and 8B.

indicate high levels. These occasional high levels do not persist for extended periods and probably do not present a decay hazard.

Although metal and plywood flashings were not removed for inspection of top and end surfaces, the side surfaces of all of these samples were free of any major checking, indicating that moisture contents did not vary widely. Some raised grain occurred, but the side checking found in other samples did not appear.

CONCLUSIONS

1. Of the six coating systems evaluated, only the polyurea paint used on samples 5A and 5B completely sealed and protected the wood and maintained excellent surface appearance for the 3-year duration of the study.

2. Flashings or covers of metal and plywood can be designed to limit moisture content to reasonable levels, thus protecting exposed beam ends from decay and maintaining the surface appearance of the wood. Plywood end and top caps performed well and are relatively easy to apply with available carpenter labor.

3. The vinyl-based plastic flashing studied was neither flexible nor strong enough to resist the stresses due to moisture changes and gradually reached a condition of complete failure within the 3-year exposure period. Similar systems based on other elastomers require further evaluation, and no general conclusions for this type of flashing is implied.

* * * * * * *

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

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PNW-264 November 1975

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EVALUATION OF THE BOEING-VERTOL 107 HELICOPTER AND SPRAY SYSTEM FOR FOREST APPLICATION OF INSECTICIDE

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by

Richard D. Orchard, *Biological Laboratory Technician*

and

George P. Markin, *Project Leader*

ABSTRACT

The distribution of insecticide sprays produced from a Boeing-Vertol 107 helicopter and spray system was evaluated under open ground conditions. The Vertol produced a spray pattern similar to that of other helicopters and was found suitable for forest spraying. The swath width varied with the nozzle arrangement on the boom. The outboard nozzle arrangement resulted in the widest acceptable swath width, the lowest deposit across the swath, and the lowest spray recovery. The inboard nozzle arrangement resulted in a moderate swath width, the highest deposit across the swath, and the highest percent spray recovery.

Keywords: Helicopters, pesticide application methods, spraying (-pest control.

INTRODUCTION

An aerial spray program to control the Douglas-fir tussock moth with the insecticide DDT was planned for late spring and early summer of 1974. This involved several hundred thousand acres in parts of northeastern Oregon, southeastern Washington, and western Idaho. Because helicopters have the ability to fly slower and closer to the target, thus applying sprays in mountainous areas with more accuracy, they were chosen by the Forest Service over conventional fixed-wing crafts to apply the pesticide.

The Forest Service anticipated a helicopter shortage because (a) the total spray area was large, (b) each unit had to be sprayed within a specified time interval, and (c) most helicopters used for agricultural spraying have small pay loads. In light of this potential shortage, the Aerial Applications Project of the Pacific Northwest Forest and Range Experiment Station has evaluated the Boeing-Vertol 107 helicopter and spray system for forest application of insecticide. The Vertol 107 is a very large double-rotored helicopter commonly used for aerial logging in the Northwest.

DESCRIPTION OF SPRAY EQUIPMENT

The helicopter and spray system (fig. 1) were furnished and operated by Columbia Construction Helicopters, Inc.,

Figure 1.--Boeing-Vertol 107 helicopter and spray system: (A) helicopter, (B) helicopter and spray system in flight, (C) left spray boom on helicopter.

of Portland, Oregon.[1/] The helicopter has double rotors and twin turbine engines. Each rotor blade is 25 feet (7.62 m) long, with 33 feet, 4 inches (10.16 m) between the forward and aft rotor shaft. Figure 2 shows the horizontal position of the forward and aft rotor relative to the position of the boom. The gross weight of the ship is 19,000 pounds (8618.4 kg) with a pay load of approximately 8,000 pounds (3628.8 kg). The spray system was a prototype designed by Columbia Construction Helicopters, Inc. The internally mounted system essentially consisted of a 250-gallon (946.35-liter) aluminum spray tank, two gasoline engines with direct drive pumps, a left and right spray boom, and a cross-over boom. The spray tank would presumably be replaced with an 800- to

[1/] The use of trade, firm, or corporation names is for the information and convenience of the reader. Such use does not constitute endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

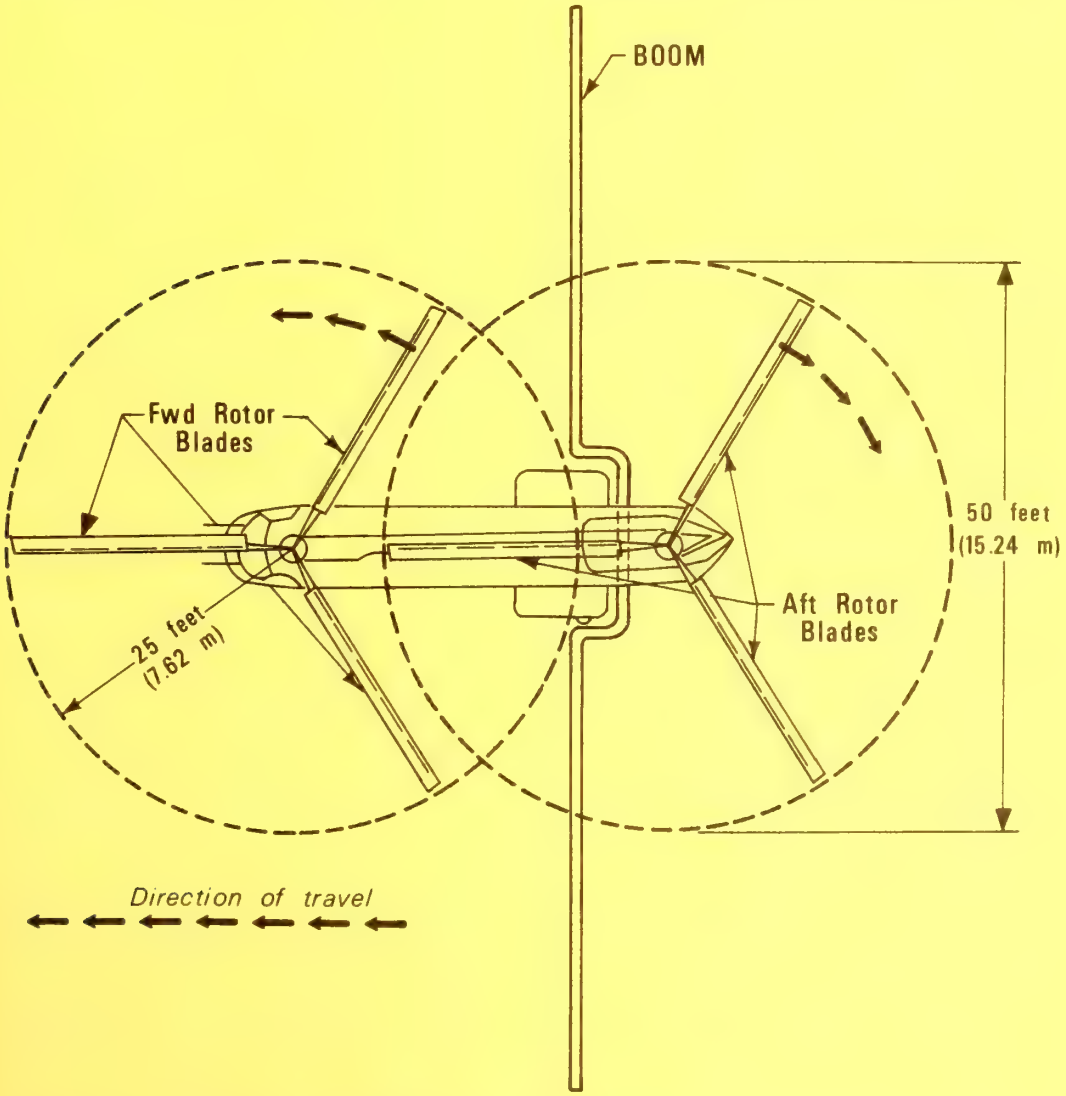

Figure 2.--Schematic showing the horizontal position of the forward and aft rotor relative to the boom.

1,000-gallon (3028.32- to 3785.4-liter) capacity tank for operational use. The two gasoline-driven engines with direct drive pumps were rated at 8.5 horsepower each, with a pump capacity of approximately 50 gallons (189.27 liters) per minute at 40 pounds per square inch (2.76×10^6 dyne/cm^2). A 12-volt battery was used for starting the engines. The spray booms were made of aluminum with rubber hoses connecting the crossover spray boom to the left and right spray boom. The crossover boom was 2-inch (5.08-cm) pipe approximately 15 feet (4.57 m) long. The left and right spray booms had two diameter reductions from inboard to outboard, which were from 2 inches (5.08 cm) to 1-1/2 inches (3.81 cm) to 1 inch (2.54 cm). Each boom was approximately 41 feet (12.50 m) long, making the total span of the booms 97 feet (29.57 m). The booms were supported by aluminum tubing and stainless steel cable leading from the airframe hard points to various points on the boom.

TEST PROCEDURE

The purpose of these tests was to obtain data concerning the swath width and deposit pattern produced by the Vertol 107 helicopter and spray system. The test procedure used was similar to that used by Orchard et al. (1974). The spraying speed, atomization, pressure, nozzle size, and spray height were constant; therefore the only variable tested was nozzle arrangements along the boom which were (1) evenly spaced, (2) inboard, or (3) outboard.

The spray formulation used was No. 2 fuel oil plus a fluorescent tracer. To each gallon (3.78 liters) of spray, 3.785 g (0.1 percent weight to volume) of the fluorescent tracer Rhodamine B Extra Base was added to facilitate deposit assessment.

Initially, the spray system was calibrated at a spray pressure of 40 pounds per square inch (2.76×10^6 dyne/cm^2) for an application rate of 1 gallon per acre (9 liters/ha) and assumed swath width of 30 feet (91.44 m). For flights 13-16, the spray system was calibrated for a 400-foo (121.92-m) swath to determine whether t swath width could be extended. To determine whether the spray was being delivered at equal rates throughout the boom, flow rates were established from nozzles at two inboard and two outboard positions on the boom. The formulation was sprayed through the nozzles and collected for 1 minute, then measured in a graduate cylinder, thus providing the flow rate per minute. All nozzles were oriented downward at 90° with respect to the line of flight. The nozzle arrangement on the boom for each treatment parameter is shown in figure 3.

The procedure used for determining the spray distribution was similar to that reported by Isler and Yuill (1964) for fixed-wing aircraft and by Isler and Maksymiuk (1961) for helicopters. A 500-foot (152.4-m) rotating platform was used for holding the deposit sampling surfaces. Sampling surfaces consisted of one 6- by 6-inch (15.24- by 15.24-cm) aluminum plate and one white 4- by 5-inch (10.16- by 12.7-cm) Kromekote card placed at 10-foot (3.05-m) intervals along the entire length of the platform. The platform was rotated for each test flight until it was perpendicular to the prevailing wind. The aircraft was flown upwind over the platform at a predetermined spot and at a designated speed and altitude. The spray was turned on 500 feet (152.4 m) downwind of the platform and turned off 1,500 feet (457.2 m) upwind of the platform. After turning off the spray, the pilot continued in a straight line for 5 seconds, then made a large turn and landed downwind of the platform so that the air currents in the direct vicinity of the sampling stations would not be disturbed.

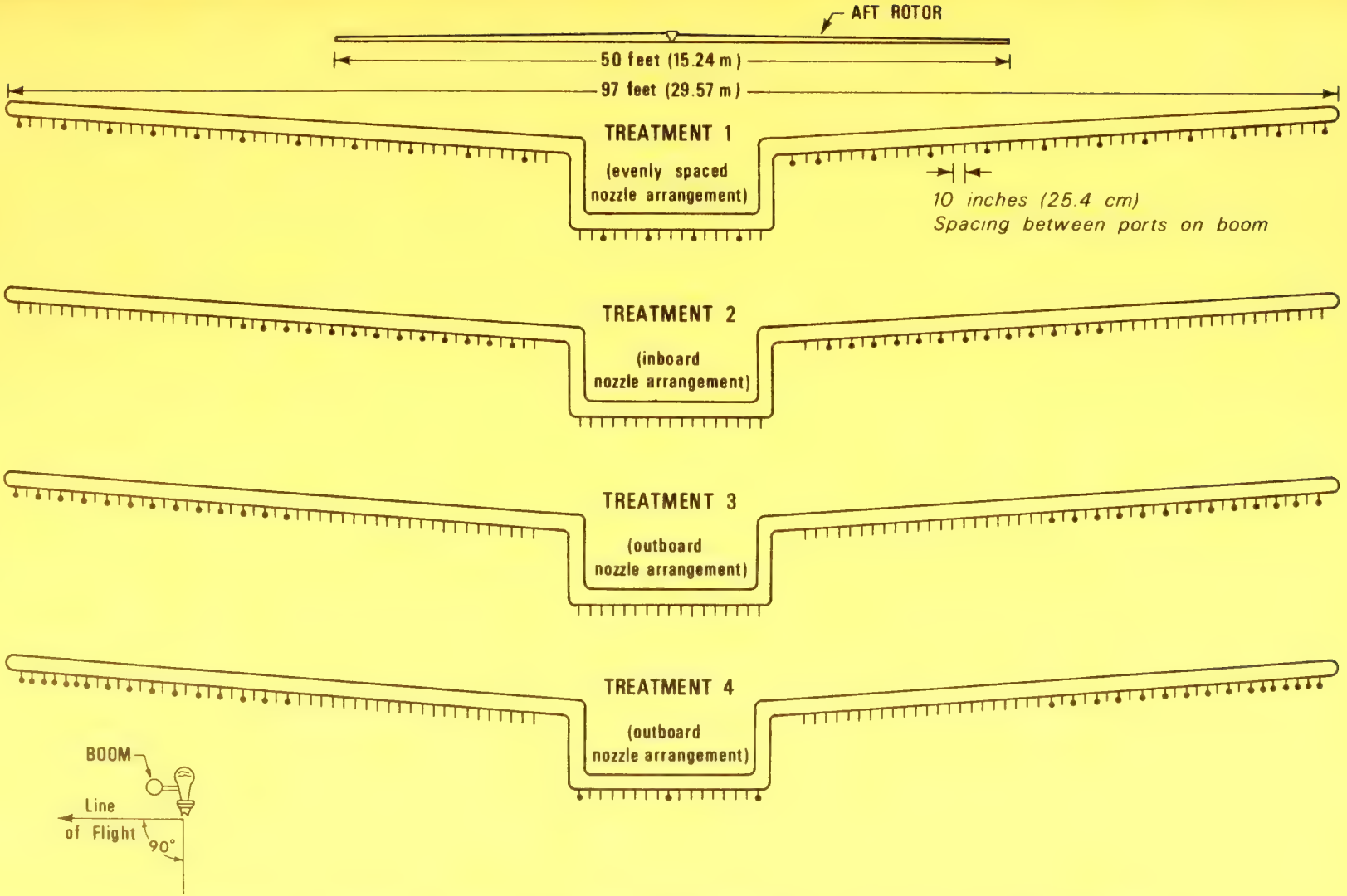

Figure 3.--Schematic showing the nozzle arrangement on the boom for each treatment.

The meteorological conditions were monitored for each test flight, as shown in table 1. Most flights were made in the early morning, when spraying conditions are usually favorable. Of 16 flights conducted, 5 were discarded because the wind changed direction during the flight causing a large part of the spray to miss the platform.

The spray was allowed to settle for 15-20 minutes; then the deposit sampling surfaces were collected and placed in slotted boxes to prevent smudging of drops and contamination of one surface by another. The boxes were then transported to the laboratory for analysis.

The spray drops on the white Kromekote cards were counted and size measured with a Quantimet 720 image analyser and ultraviolet illuminator. The spray atomization was determined by the drop-size spectra method (Maksymiuk 1964). The number of drops are expressed in number per square centimeter of surface area, and the size (atomization) is expressed as the volume median diameter (vmd).[2/]

The spray deposit was washed from each of the aluminum plates with 10 ml of 95-percent ethanol. The deposit recovered from the plates was quantitated fluorometrically, using a Model 430 Turner Spectrofluorometer, similar to the method described by Yates and Akesson (1963). The quantity of spray is expressed in gallons per acre (gpa) and liters per hectare.

RESULTS AND DISCUSSION

Calibration

Flow rates at the different locations along the boom are shown in table 2. The flow rate for nozzles located on the left inboard, left outboard, and right outboard part of the boom were very nearly equal with very little variation. The right inboard nozzle had a flow rate 5.9 percent greater than at the other locations and was consistently greater for each of the four replications. Since the difference was small, we did not determine whether this difference was a result of the spray system design or the nozzle. The gasoline-engine-driven spray pump, which is independent of the helicopter engine, allowed for easy calibration on the ground.

Swath Width

Table 3 shows the swath width, swath deposit, percent recovery, and atomization for each test flight. For our purpose, an acceptable swath width was defined as that portion of the swath having a deposit level of 0.1 gpa (0.935 liter per ha) or greater at each sampling point throughout the swath. A comparison of the nozzle arrangement on the boom shows that the outboard arrangement (treatment 3) resulted in a wider acceptable swath width. The swath width obtained with the outboard nozzle arrangement calibrated for a 400-foot (121.92-m) swath (treatment 4) was somewhat smaller but resulted in a higher average swath deposit. The inboard nozzle arrangement (treatment 2) resulted in a wider swath width than the evenly spaced nozzle arrangement (treatment 1). By placing the nozzle outboard, more spray is drawn into the vortices and released over a wider area as the vortices spread out and dissipate. Some of the flights were slight crosswind flights. The average swath width for the 11 flights was 254 feet (77.42 m).

The degree of atomization is a critical factor in determining swath widths. As the spray is further atomized, that is, drops become smaller, it is carried farther by the vortices and is affected more by prevailing meteorological conditions, hence more drift. Consequently,

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[2/] Volume median diameter (vmd) is the drop diameter satisfying the requirement that half of the volume of liquid is in drops smaller and half in drops larger than the vmd.

Flight number	Date (1974)	Time (a.m.)	Wind condition and speed, m/h (m/sec)				Wind direction (degrees)		Air temperature, °F (°C)						Relative humidity (percent)			Sky condition
			Gusty	at 4 feet (1.22 m)	at 16 feet (4.88 m)	at 40 feet (12.19 m)	at 4 feet (1.22 m)	at 40 feet (12.19 m)	at 4 feet (1.22 m)	at 8 feet (2.44 m)	at 16 feet (4.88 m)	at 24 feet (7.32 m)	at 32 feet (9.75 m)	at 40 feet (12.19 m)	at 4 feet (1.22 m)	at 16 feet (4.88 m)	at 40 feet (12.19 m)	
1	4-16	7:10	no	1 (0.45)	2 (0.89)	3 (1.34)	230	260	34 (1.1)	36 (2.2)	36 (2.2)	36 (2.2)	36 (2.2)	35 (1.7)	100	100	100	clear
2	4-16	7:30	no	1 (.45)	1-2 (.45-.89)	1 (.45)	270	260	36 (2.2)	38 (3.3)	36 (2.2)	38 (3.3)	37 (2.8)	36 (2.2)	100	100	--	clear
3	4-16	8:12	no	3 (1.34)	2 (.89)	2 (.89)	270	280	41 (5.0)	40 (4.4)	40 (4.4)	41 (5.0)	40 (4.4)	40 (4.4)	100	100	100	clear
4	4-16	8:50	no	1-2 (.45-.89)	1 (.45)	1 (.45)	285	300	42 (5.6)	43 (6.1)	42 (5.6)	46 (7.8)	43 (6.1)	42 (5.6)	100	98	100	clear
7	4-17	8:00	no	0-1 (0-.45)	0-1 (0-.45)	0-1 (0-.45)	180	170	40 (4.4)	40 (4.4)	41 (5.0)	40 (4.4)	41 (5.0)	42 (5.6)	100	100	100	clear
8	4-17	8:50	no	1-2 (.45-.89)	1-2 (.45-.89)	2 (.89)	120	100	48 (8.9)	48 (8.9)	47 (8.3)	49 (9.4)	47 (8.3)	47 (8.3)	90	100	100	clear
9	4-17	9:05	no	1 (.45)	2 (.89)	3-4 (1.34-1.79)	175	100	47 (8.3)	48 (8.9)	48 (8.9)	50 (10.0)	50 (10.0)	49 (9.4)	90	100	95	clear
10	4-17	10:05	slight	0 (0)	1 (.45)	1-2 (.45-.89)	--	20	54 (12.2)	53 (11.7)	52 (11.1)	54 (12.2)	54 (12.2)	54 (12.2)	80	90	82	clear
12	4-18	7:00	yes	2 (.89)	5 (2.24)	>8 (73.58)	310	290	44 (6.7)	45 (7.2)	46 (7.8)	46 (7.8)	47 (8.3)	47 (8.3)	100	100	100	overcast
13	4-18	8:20	no	1-2 (.45-.89)	1-2 (.45-.89)	1-2 (.45-.89)	310	300	48 (8.9)	47 (8.3)	49 (9.4)	48 (8.9)	48 (8.9)	48 (8.9)	100	100	100	overcast
15	4-19	8:45	yes	3-5 (1.34-2.24)	4-5 (1.79-2.24)	6 (2.68)	180	130	44 (6.7)	45 (7.2)	45 (7.2)	43 (6.1)	44 (6.7)	44 (6.7)	100	100	100	overcast

Table 2--Flow rate data for nozzles positioned at various points along the boom

Location of nozzle	Flow rate for SS 8020 nozzle tip at 40 pounds per square inch (2.76×10^6 dyne/cm^2)				
	Run 1	Run 2	Run 3	Run 4	Mean
	- - - - - *Gallons per minute (liters/min)* - - - - -				
Left inboard	2.04 (7.72)	2.07 (7.84)	2.06 (7.80)	2.04 (7.72)	2.05 (7.76)
Left outboard	2.04 (7.72)	2.05 (7.76)	2.03 (7.68)	2.00 (7.57)	2.03 (7.68)
Right inboard	2.12 (8.02)	2.18 (8.25)	2.17 (8.21)	2.12 (8.02)	2.15 (8.14)
Right outboard	-- (--)	2.04 (7.72)	2.02 (7.65)	1.99 (7.53)	2.02 (7.65)
Mean	2.07 (7.84)	2.08 (7.87)	2.07 (7.84)	2.03 (7.68)	2.06 (7.80)

Table 3--Swath width, swath deposit, percent recovery, and atomization for individual test flights using SS 8020 nozzle tips at a constant pressure of 40 pounds per square inch (2.76×10^6 dyne/cm^2), spray height of 70 feet (21.34 m), and spray speed of 90 miles per hour (40.23 m/sec)

Treatment and flight number	Swath width, feet (m)		Average swath deposit		Percent recovery	Atomization, μm (vmd)
	Calibrated	Actual[1/]	Gallon per acre (liters/ha)	Drops per square centimeter		
1--evenly spaced nozzle arrangement:						
1	300(91.44)	310(94.49)	0.442(4.13)	49	47	150
2	300(91.44)	160(48.77)	.676(6.32)	70	40	158
3	300(91.44)	220(67.06)	.353(3.30)	53	31	151
4	300(91.44)	180(54.86)	.459(4.29)	71	33	150
Mean	--	218(66.45)	.482(4.51)	61	38	152
2--inboard nozzle arrangement:						
7	300(91.44)	250(76.20)	.569(5.32)	80	51	113
8	300(91.44)	260(79.25)	.420(3.93)	68	40	121
9	300(91.44)	220(67.06)	.498(4.66)	47	40	130
Mean	--	243(74.07)	.495(4.63)	65	44	121
3--outboard nozzle arrangement:						
10	300(91.44)	310(94.49)	.201(1.88)	34	24	136
12	300(91.44)	320(97.54)	.382(3.57)	29	42	152
Mean	--	315(96.01)	.292(2.73)	32	33	137
4--outboard nozzle arrangement:						
13	400(121.92)	330(100.58)	.441(4.12)	77	38	144
15	400(121.92)	230(70.10)	.462(4.32)	50	30	150
Mean	--	280(85.34)	.451(4.22)	64	34	147

[1/] The swath width is that part of the swath having 0.1 gallon per acre (0.935 liters/ha) or greater at each sampling point.

the overall physical swath width will be wider, but the deposit level within the swath may not be acceptable.

Spray Deposit and Pattern

As shown in table 3, the highest swath deposit, both in terms of gallons per acre (liters per ha) and number of drops per square centimeter, was achieved by the inboard nozzle arrangement treatment. The outboard nozzle arrangement (treatment 3) resulted in the widest swath width, the smallest deposit across the swath in terms of gallons per acre (liters/ha) and number of drops per square centimeter, and the smallest percent recovery.

Figures 4-7 show the spray pattern of individual flights for each test. There are no two patterns alike, but there are similarities. The swath width produced by this helicopter is wider, but the deposit pattern similar, to the smaller single rotor helicopters and suitable for forest spraying. The effects of the double rotor on spray distribution are unknown, but it is thought to reduce the strength or velocity of the vortex. By using a dyed spray, the vortices produced by the rotor blades become visible and can be observed as the spray is entrapped by these vortices. Visual observation shows the Boeing 107 having a weaker vortex than the Bell 205. Since the distance between the boom and rotor blades is much greater on the Boeing 107 than on the Bell 205, there may not have been enough spray entrapped in the vortex to portray its full size and intensity.

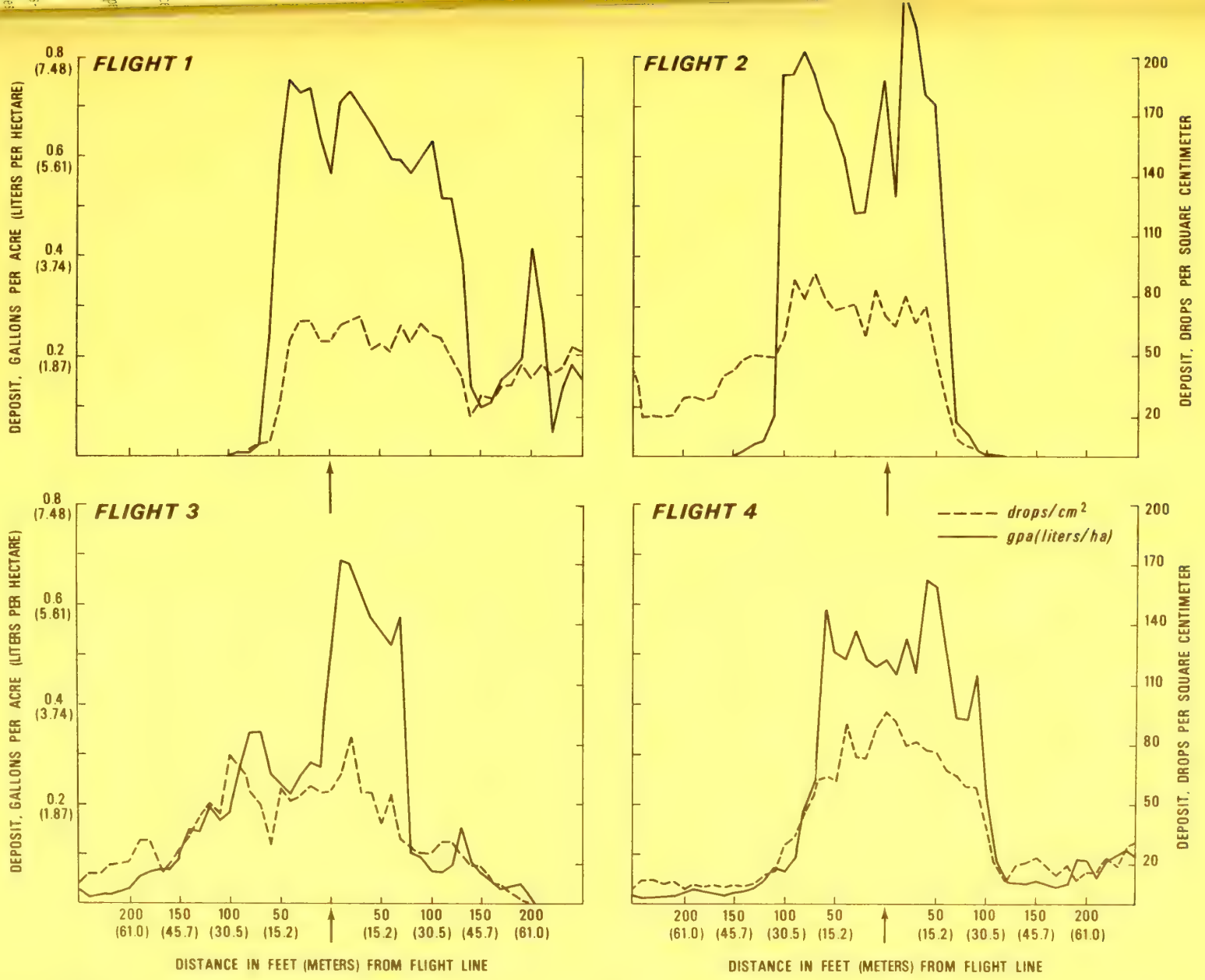
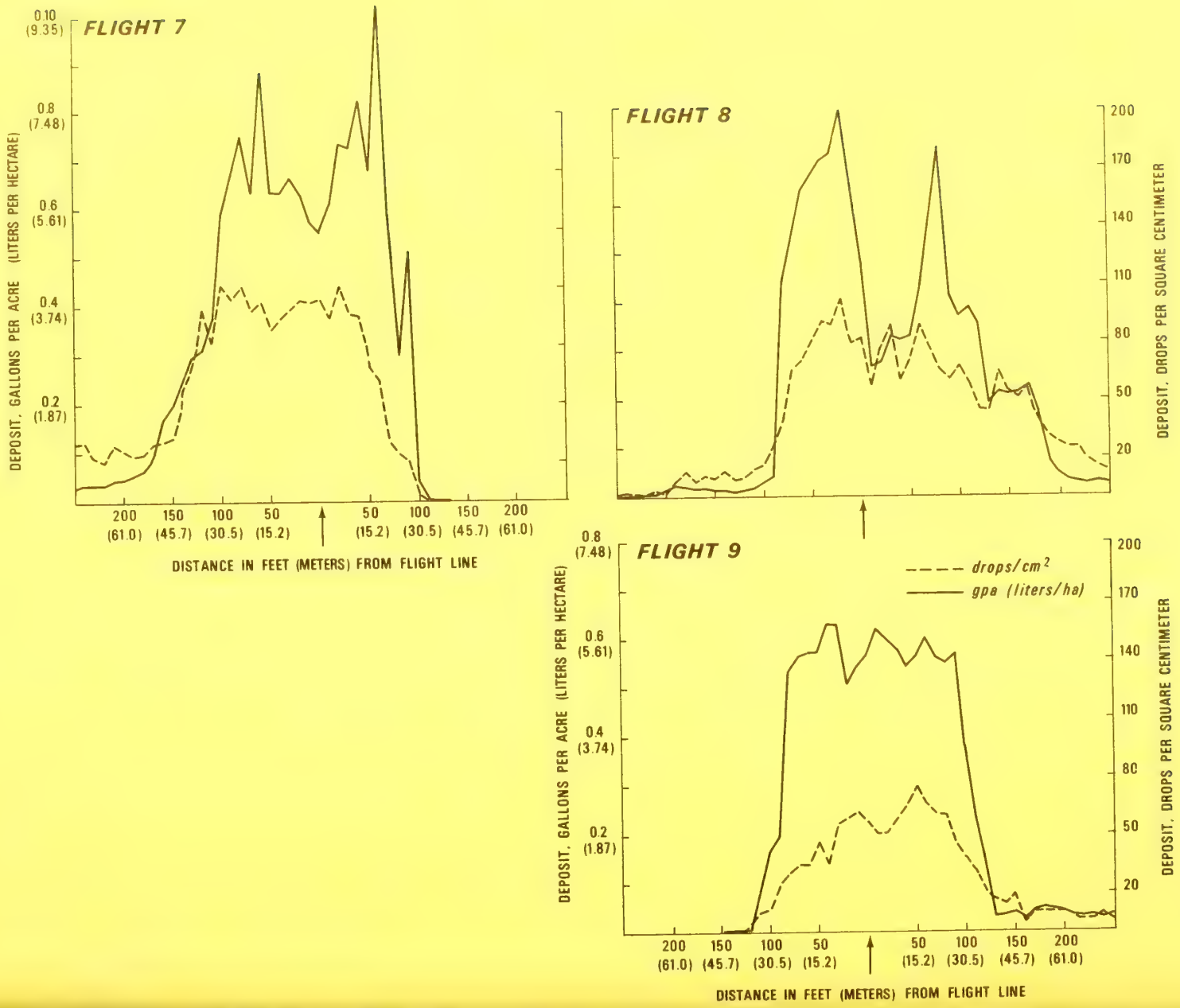


Figure 4.--Spray pattern for individual flights. Treatment 1: Evenly spaced nozzle arrangement, calibrated for a 300-foot (91.44 m) swath.



individual flights. Treatment 2: Inboard nozzle arrangement;

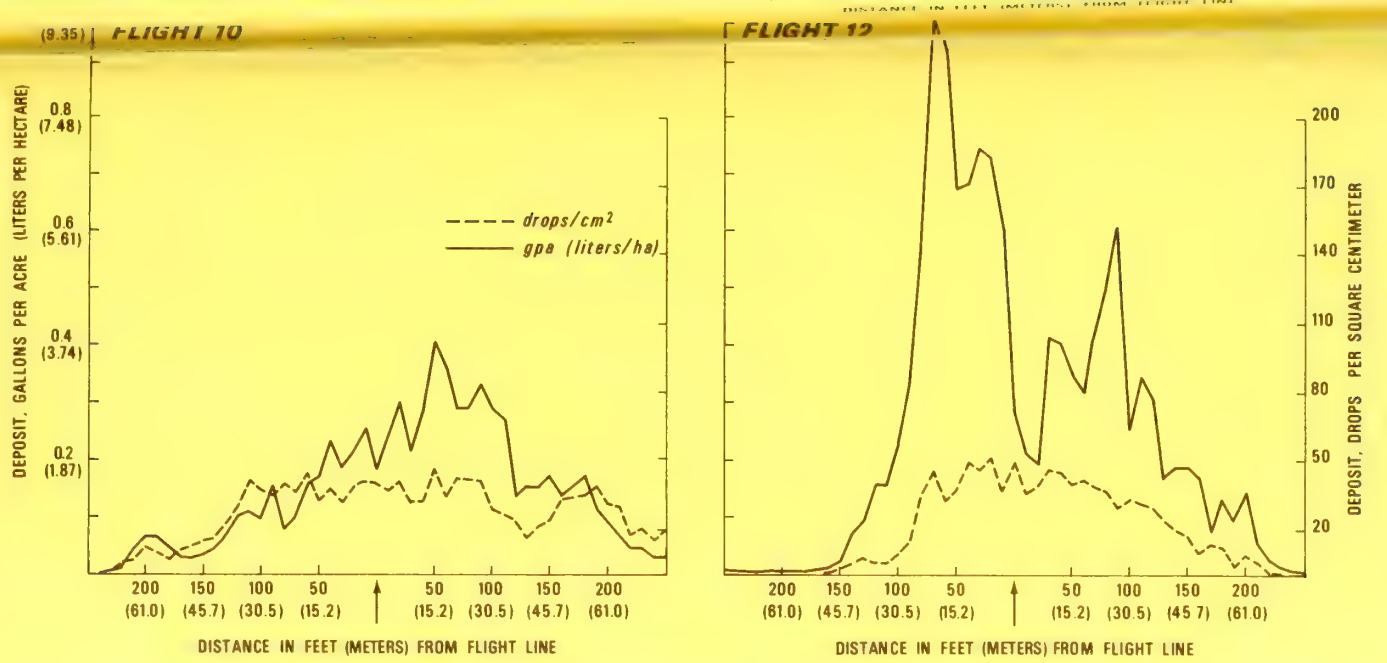


Figure 6.--Spray pattern for individual flights. Treatment 3: Outboard nozzle arrangement, calibrated for a 300-foot (91.44 m) swath.

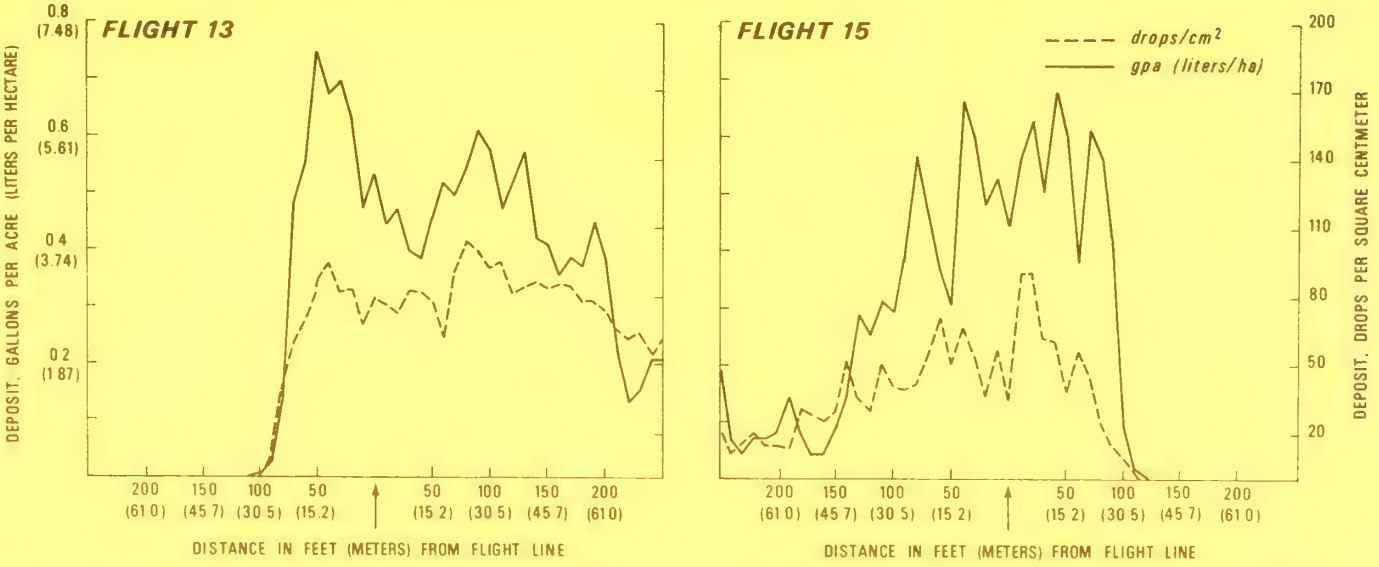


Figure 7.--Spray pattern for individual flights. Treatment 4: Outboard nozzle arrangement, calibrated for a 400-foot (121.92 m) swath.

SPRAY RECOVERY AND ATOMIZATION

On the average, 38 percent of the spray was recovered on the sampling platform, with a range of 24-51 percent. The spray recovery rate is about the same as that from other helicopters operating under similar conditions. The average atomization for all test flights was 141-μm vmd. The volume median diameter is slightly, but consistently, smaller for the inboard nozzle arrangement flights. Figure 2 shows that the forward rotor blade tips are directly over the inboard part of the boom. The vortices formed by both rotor tips may be causing an increased shear over a sufficient number of nozzles to result in a lower volume median diameter.

CONCLUSIONS

1. The right inboard nozzle consistently had a higher flow rate than nozzles at other locations.

2. The spray system was very easy to calibrate, and the boom could be rotated to adjust nozzle orientation with respect to the line of flight.

3. The outboard nozzle arrangement produced the widest swath width, the smallest deposit across the swath, and the smallest percent recovery.

4. The inboard nozzle arrangement gave a moderate swath width, with the largest deposit across the swath and the highest spray recovery.

5. The inboard nozzle arrangement resulted in a smaller volume median diameter.

6. In general, it was concluded that the Boeing-Vertol 107 helicopter and prototype spray system was a satisfactory tool for aerial application of pesticides. The swath deposit, pattern, and spray recovery were found to be typical of that of other spray systems operated under similar conditions. General operation of the helicopter, maneuverability, and ease of working with the spray system in changing nozzles and calibration were all found to be satisfactory. It is expected that the prototype spray system would be altered for operational use, such as replacing the existing spraytank with a larger one and installing an emergency spray dump.

7. This aircraft should be further tested to establish the effect of rotor wake, vortices, and downwash on dispersal of the spray under open ground and forest conditions.

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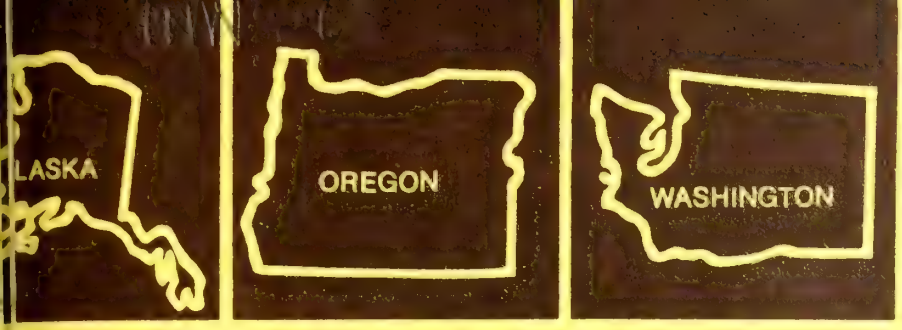

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-265 December 1975

JUL 19

IMPROVED LABORATORY METHODS FOR TESTING GRAFT COMPATIBILITY IN DOUGLAS-FIR

by

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ABSTRACT

Improved laboratory methods for preparing microscope slides from Douglas-fir graft unions are presented. Descriptions of equipment and supplies and graft collection, sectioning, and staining methods are all outlined in detail. Sections from unembedded graft unions are cut with a sliding microtome. A number of modifications of the traditional safranin and fast green staining method are made to obtain the best results in the shortest time. The cut sections are placed in specially designed staining baskets and transferred through a 14- or 18-step staining schedule. Solution concentrations, the time sections are left in each solution, as well as methods for correcting under- and over-staining, are listed. Procedures for preparing both temporary and permanent slides are described. The methods are fast and accurate. Excellent staining can be achieved by technicians with little or no formal training. The methods also work well for many other conifers and are effective on normal stems as well as graft unions.

KEYWORDS: Grafting, Douglas-fir.

EST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

INTRODUCTION

Graft incompatibility has hindered Douglas-fir orchardists for a number of years[1/] and will continue to be a problem until highly graft-compatible rootstocks are available for general use. Simplified laboratory methods for detecting incompatibility in Douglas-fir grafts were reported,[2/] but the methods were not very efficient when hundreds or thousands of unions were tested.

Quality, accuracy, reproducibility, speed, and simplicity are requirements for efficient laboratory methods when many slides must be made. After 10 years of graft testing at the Corvallis laboratory, we have developed such methods. Descriptions of these methods follow, written in detail so that people unfamiliar with microtechnique procedures, equipment, and supplies can produce satisfactory results without additional information or training. Graft collection, microtome requirements and adjustments, staining equipment and solutions, sectioning and staining techniques, and mounting equipment and materials are discussed in separate sections.

Graft Collection Techniques

Graft unions are collected in late summer or early fall of the year after grafting (15-18 months). Collection after the cambium has ceased growth is best because the bark is tightly attached to the stem. Bark retention on stained sections is necessary for compatibility analysis of some species. On Douglas-fir grafts it is helpful but not necessary. Douglas-fir grafts that are collected in the spring before cambial growth starts the second year do not have the anatomical structures required to indicate whether the grafts are compatible or incompatible and are worthless for test purposes.

The unions should be severed from the stock and scion by cuts approximately 1 cm above and 1 cm below the graft union (fig. 1A). Sharp scissor-type pruning shears are best for severing unions. The severed union should be between 3 and 5 cm long. When field collectors become familiar with union anatomy, laboratory preparation time can be reduced by cutting through the area of the union where sections will be made (fig. 1B). The upper cut should be made at a right angle to the long axis of the stem. This cut is usually the area of the least grafting technique deformity and is usually the smoothest area of the union. If the stock and scion were both the same diameter when grafted, the top cut is made where stock and scion match on both sides of the stem. The lower cut, which severs the graft union from the stock, is made approximately 1 cm below the union. It is diagonal to the long axis of the stem, allowing the technician to quickly identify the end of the graft from which sections are not to be made.

After the unions are cut from the stock and scion, they are placed into 8- to 30-ml shell vials or small containers filled with a preservative solution of 30- to 50-percent alcohol. Alcohol concentrations above 50-percent should not be used because the unions become too hard for easy microtome sectioning. If unions are accidentally preserved in alcohol solutions that cause the tissues to harden, they can be softened before sectioning by overnight soaking in water. Either ethanol or isopropanol can be used as a preservative.

[1/] Copes, D. L. 1970. Initiation and development of graft compatibility symptoms in Douglas-fir. Silvae Genet. 19(2-3): 101-107.

[2/] Copes, D. L. 1967. A simple method for detecting incompatibility in 2-year-old grafts of Douglas-fir. U.S. Dep. Agric. For. Serv. Res. Note PNW-70, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

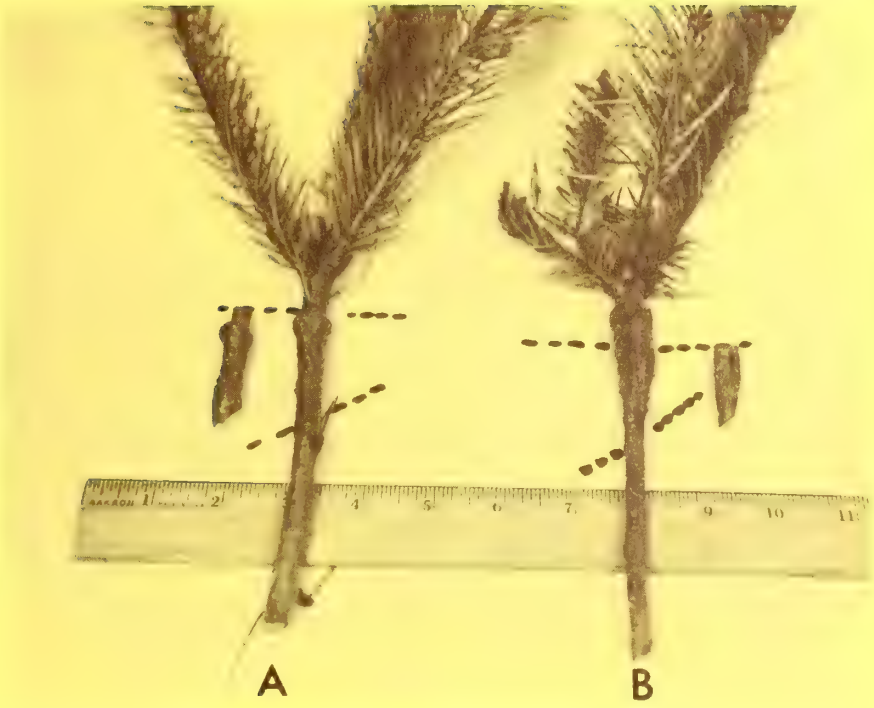

Figure 1.--Two methods of severing grafts from the root-stock and scion. Graft A is cut slightly above and below the union. In graft B the top cut is made through the area of the union where sections are to be sliced. A ruler calibrated in inches is shown for scale.

Grafts should remain in the alcohol solution at least 24 hours before sectioning and can be stored in the alcohol indefinitely. Each container should be clearly marked with the scion clone number and stock number.

Microtome Requirements and Adjustments

A sliding microtome should be used rather than attempting to slice free-hand sections with a knife or razor blade. Rotary microtomes are also unsatisfactory. One example of a satisfactory microtome is shown in figure 2. The sliding microtome should have an automatic advancement (feed) mechanism and a knife clamp that is large enough to hold a 200- to 250-mm knife. Large knives are better than small ones because more grafts can be cut before resharpening is needed.

To cut good sections a sharp knife is essential. One indicator of a dull cutting edge is alternate thin and thick sections, although this can occur if the tilt angle adjustment allows the knife to drag across the surface of the graft on the return stroke. Another indicator of a dull knife is sections with ragged and torn bark tissues. Approximately 35 to 100 grafts can be cut on each 2.5 cm of knife edge. The actual number depends upon graft size and the alcohol concentration used as the preservative. Knives should be sharpened when the entire cutting edge is dull. Sharpening should be done by a commercial or medical knife sharpening company.

Correct positioning of the knife in the microtome is important. The vertical (clearance or tilt) angle of the knife should be adjusted so that

Figure 2.--One type of suitable sliding microtome. A 250-mm knife is clamped into a heavy-duty microtome knife holder.

it is as flat as possible. The top of the graft should not touch on the lower surface of the knife when the knife is returned to the forward cutting position. The cutting edge of the knife and the knife holder should be so oriented that the knife edge meets the graft at a 60° horizontal (slice) angle. Trial and error testing will help determine which vertical and horizontal angles work best. Sections of poor quality are produced when improper angle adjustments are used. The correct angles should be checked after a knife is sharpened, as incorrect sharpening sometimes changes the angles that work best.

The base of the microtome closest to the technician should be elevated about 2.5 cm higher than the far end. Elevating will cause the knife to automatically slide away from the operator and specimen and greatly reduces the chance of technicians accidentally getting cut on the exposed knife edge.

The specimen advancement (feed) mechanism should be set to cut sections 20 to 26 um thick. Such sections are thin enough for easy microscope viewing, yet thick enough to permit them to be transferred without damage from the last staining baskets to microscope slides.

Staining Equipment and Solutions

Nine staining baskets should be constructed from small-mesh wire screen (fig. 3). Screen sizes 16 by 18 mesh or 1/8-in are both satisfactory. Copper screen is best because it does not react with the chemicals used in staining. Galvanized screen is suitable if copper is not available. The wire must be heavy enough to retain its shape when bent into the correct form.

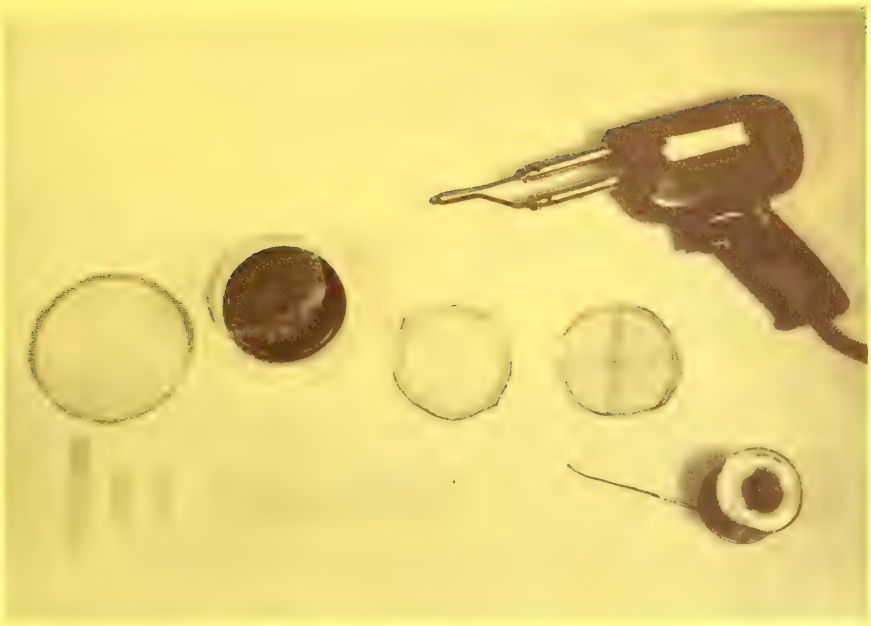

Figure 3.--Materials and equipment needed to fabricate staining baskets. The sides of the baskets are formed by bending the circular piece of wire screen over a bottle (8-cm diameter). The wire strips that make the inner dividers are shown on the lower left. A ruler (cm) is shown for scale.

The staining baskets are designed to fit into the bottom half of a petri dish. They are circular, approximately 8 cm in diameter and 1 cm high. The main body (bottom and sides) of each basket is made from a single piece of screen 10 cm in diameter (fig. 3). The sides of the baskets are made approximately 1 cm high by bending the screen over the end of a circular disk, tube, or bottle that is slightly smaller than the inside diameter of the bottom half of a petri dish. The interior of each molded basket is divided into four compartments by soldering one 8- by 1-cm and two 4- by 1-cm pieces of screen into position (fig. 3). The dividing strips must be carefully soldered to the bottom and sides of the basket or the thin graft sections might slip under the dividers and become mixed with sections from other grafts in adjacent compartments.

The following materials are used in the staining and sectioning processes: one medium-sized camel's-hair brush; one cover-glass forceps with flat, bent ends; one pointed-tip forceps; a small syringe; one roll of heavy-duty aluminum foil; a timing clock; and two sponges or absorbent paper towels.

The table or bench top where sectioning and staining are done should be covered for protection. Heavy paper effectively prevents damage from spilled water and chemicals and can be replaced when necessary.

Glass containers should be used for staining solutions because some of the solutions will dissolve plastics and other materials. Three petri dishes are filled with water and placed to the left side of the microtome (fig. 4). On the right

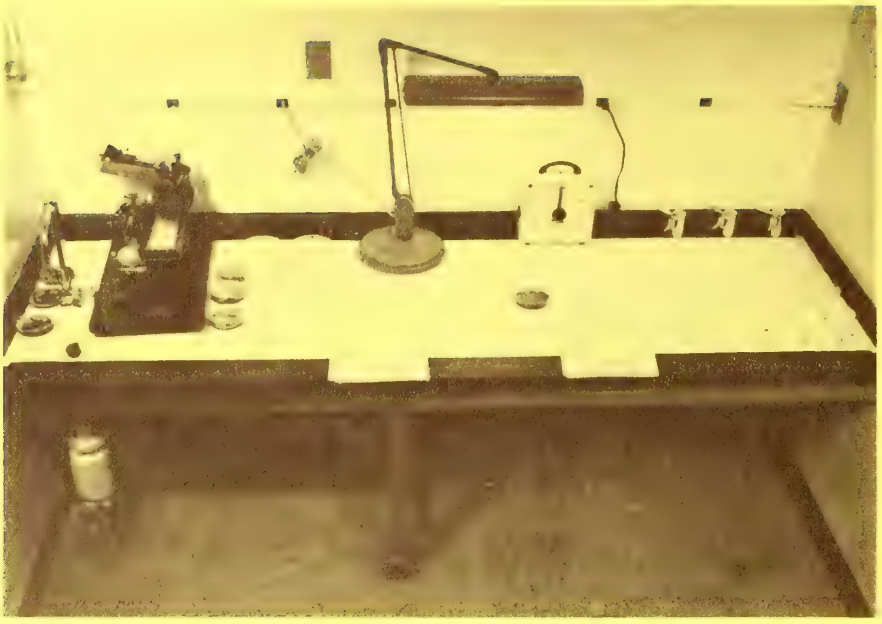

Figure 4.--Laboratory organized for a right-handed technician. The numbers correspond to the step numbers in figure 5.

side of the microtome 23 dishes and 2 beakers or jars are placed in the correct order and filled with the proper solutions (fig. 4). If a person is left-handed, the position of the microtome and dishes should be reversed.

Petri dishes should be filled with approximately 50 ml of solution. The upper edges of the baskets and the compartment dividers should always be above the top level of the solutions. If too much solution is used, sections will float between compartments and graft identity will be confused. Alcohol rapidly evaporates when left uncovered, so the open petri dishes should be covered when not in use. Periodic refilling and solution changes are required to replace evaporated liquid and to eliminate contaminated or dirty solutions.

The first three petri dishes on the right side of the microtome (step 2, fig. 5) are filled with a 1-percent safranin solution in water (1 g safranin-0 in 100 ml H_2O). Additional safranin solution should be prepared and stored until needed.

The next two containers (steps 3 and 4) are 1000-ml beakers or large jars filled with tap water. The water is used to rinse excess safranin stain from the baskets and sections and must be changed whenever it becomes darkly colored or the excess stain will not be removed. The next petri dish is filled with a 1:1 solution of water and 95-percent ethanol (step 5). The following dish contains a 0.5-percent solution of picric acid in 95-percent ethanol (0.5 g of picric acid in 100 ml of 95-percent ethanol) (step 6). Picric acid rapidly removes loosely bound safranin from cell areas where it is not desired.[3/] Other acids can

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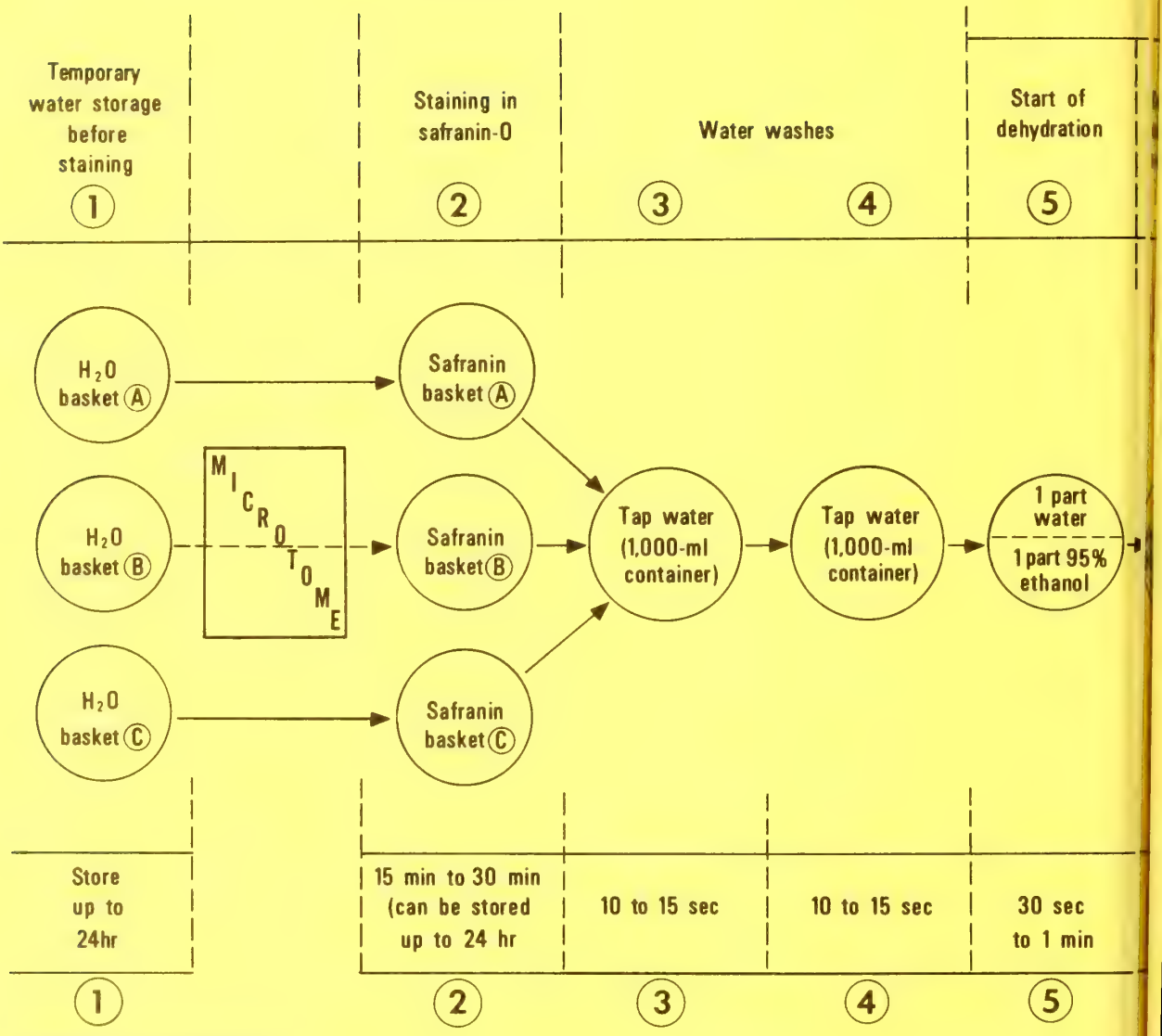
[3/] Johansen, D. A. 1940. Staining procedures - safranin and combinations. In Plant microtechnique, p. 80-82. McGraw-Hill Book Co., Inc., New York and London.

Figure 5.--Diagram of proper



TIMING SCHEDULE

be substituted for picric acid, but the technician must determine the correct concentration for each.

The next petri dish contains 50 ml of 95-percent ethanol and five drops of concentrated ammonia hydroxide (NH_4OH) (step 7). To maintain the proper solution level in the petri dish, additional NH_4OH solution can be prepared by mixing 100 ml of 95-percent ethanol and 10 drops of NH_4OH. The NH_4OH stops the destaining action that was started by the picric acid in step 6. The following petri dish contains 95-percent alcohol (step 8). The alcohol dilutes or washes off any NH_4OH transferred as contamination from the previous petri dish. The next three petri dishes are filled with 95-percent ethanol (step 9) and used as temporary storage or holding dishes until additional baskets are moved forward. Each basket is placed into only one of these dishes.

Fast green staining solution is put into the next dish (step 10). Best results are usually obtained with the following recipe: 100 ml 95-percent ethanol, 100 ml clove oil, 100 ml methyl cellosolve (2-methoxyethanol), and 0.5 g of fast green FCF (see footnote 3). If methyl cellosolve is not available, use the following recipe: 100 ml 95-percent ethanol, 100 ml clove oil, and 0.5 g of fast green FCF. If both clove oil and methyl cellosolve are unavailable, use 0.5 g of fast green FCF per 100 ml of 95-percent ethanol. Fast green stain should be prepared at least 1 day before use.

The six dishes following the fast green are filled with 95-percent ethanol (steps 11-14). Their purpose is to wash off excess fast green from the sections and baskets before the sections are mounted on microscope slides. The staining schedule ends with step 14 when temporary microscope slides are wanted.

For permanent slides, steps 15 through 18 are added. The first dish (step 15) is filled with a 1:1 solution of 95-percent ethanol and parasol (Scientific Products Co.)[4/] or xylene. The remaining dishes are filled with undiluted parasol or xylene (steps 16-18). The three dishes in step 18 are used to store the stained sections temporarily until they can be permanently mounted on microscope slides. Parasol is preferred over xylene because it is less toxic. Xylene can cause health problems after prolonged use in poorly ventilated rooms.

Sectioning Techniques

Each graft container must be given a laboratory identification number in addition to the scion and stock number marked in the field. The best technique is to write the identification number on the top of the corks or caps covering each container. Corresponding identification numbers are written in a vertical column on a 1-cm-wide strip of aluminum foil. Each number is then cut from the strip and is put into an empty basket compartment sequentially in the order that the grafts are to be sectioned. To start the procedure, three baskets are put into the dishes of water (step 1, fig. 5).

At this stage the technician is ready to begin sectioning. The first graft should be removed from its vial and trimmed through the proper union area. If it was cut through the graft union when collected (fig. 1B), no further trimming is necessary. A good quality scissor-type (not the anvil type) pruning shears or a razor blade is used to expose the area of the graft where the best match of stock and scion tissue exists. A low power hand lens or battery-powered magnifier insures that the correct union area is exposed. After trimming,

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[4/] Mention of company by name does not imply endorsement by U.S. Department of Agriculture.

the graft is tightened securely in the specimen clamp of the microtome so that the graft will not vibrate when the knife cuts the union. When a graft has a union of stock and scion tissues on only one side of the stem, the graft is turned so that the best union surface faces the knife. Proper graft positioning in relation to the knife reduces splitting and tearing and results in better cut sections.

A rubber syringe filled with tapwater is used to put several drops on top of the graft and several more drops on the edge of the microtome knife where sections are to be cut. Wetting the two surfaces allows the sections to float on the blade when they are cut and prevents them from tearing or rolling-up. The cut section is removed from the knife with a fingertip or a small camel's-hair brush before the next section is cut. The sections are placed in the staining basket compartment labeled with the same number as the vial from which the graft was taken. Four to six good sections should be cut from each graft. When these procedures have been repeated with three more grafts, all four compartments of basket A (step 1) contain cross-sections. Sectioning is continued with eight additional grafts until staining baskets B and C are completed (step 1). The three filled baskets are then blotted on the first sponge to remove excess water and are put into the petri dishes containing safranin stain (step 2). While the sections in the first three baskets are being stained, three more baskets are placed in the dishes of water on the left side of the microtome, and 12 more grafts are sectioned. This same progressive method of cutting and staining is repeated throughout the workday.

One helpful technique for difficult grafts is to place a 2.5-cm-wide strip of wet paper towel on the upper surface of the specimen before each cut is made. The paper will help prevent sections from rolling-up and, since the section will stick to the paper, the paper can be used to transfer the section from the specimen to the staining basket.

Staining Procedures

Three staining baskets (A, B, and C) should be transferred in sequence through the different dishes of the staining schedule (fig. 5). Working with three baskets at a time is efficient for one person. However, if two people are working together, six staining baskets (24 grafts) in a series is efficient. When six baskets are used, three additional petri dishes must be added to each of steps 2, 9, 14, and 18.

Staining baskets must be blotted on sponges or absorbent paper towels before being placed into the next dish. Blotting is important because excess fluid inadvertently transferred between dishes causes contamination which will reduce quality and make frequent solution changes necessary. When sponges rather than absorbent paper towels are used, the first sponge is used for blotting all basket transfers before the dish containing fast green. The second sponge is used for the dish containing fast green and all following dishes. Sponges must be washed in hot water at the end of each day.

Sections should be left in the safranin solution at least 15 to 30 minutes (step 2). Staining times of 1 to 2 hours produce slides with greater green and red contrast. Sections can be left overnight in the safranin stain if necessary. Basket A should be removed from the safranin dish and washed in the first container of water (step 3). Washing is repeated in the next dish (step 4). The basket is then moved into the water-alcohol solution where it should remain from 30 to 60 seconds (step 5). The basket is then placed into

the destaining solution of picric acid (step 6), for 15 seconds to 1 minute. If sections have been left overnight in the safranin stain, the picric acid destaining time must be increased to approximately 2 minutes or until adequate destaining has occurred. The exact time will vary according to how long the sections are left in the safranin, strength of the safranin solution, and thickness of the sections. A longer interval in the picric acid solution is indicated if safranin continues to wash out of sections and discolors the alcohol solutions in step 9. After destaining, basket A is placed into the petri dish containing alcohol and NH_4OH (step 7) for 1 to 2 minutes and then transferred to the next petri dish (step 8). It should remain in the alcohol solution for 1 to 5 minutes and then be placed into storage dish A (step 9). Baskets B and C are advanced in the same manner and are stored in dishes B and C, respectively, of step 9. Sections can remain in 95-percent alcohol solutions of step 9 for up to 1 hour without damage, but prolonged storage slowly causes the tissues to become hard and brittle.

After baskets A, B, and C are advanced to step 9, basket A is placed in the dish containing fast green (step 10). The basket should be agitated up and down several times while it is in this stain. Agitation separates overlapping sections and insures uniform staining. The basket is left in this stain for approximately 1 minute. The time that sections are in the fast green must be carefully controlled. Staining solutions become weak after continued use. Adding additional fresh stain solution to compensate for that carried out on sections and baskets normally keeps the dish at satisfactory strength. The exact time of staining in fast green will vary with section thickness, length of time the sections were left in safranin, length of time of destaining in picric acid, and the concentration of the fast green solution.

If sections under- or over-stain with fast green, correct staining can be obtained by lengthening or shortening, respectively, the time that the sections are submerged in the solution. If proper staining is still not obtained, the concentration of fast green can be either increased or decreased. Changing the time is preferred to changing the solution concentration. Sections stained in safranin 15 to 30 minutes are left in fast green for 1 minute. Thick sections and sections that have been left in safranin overnight should be stained in fast green an additional minute.

Basket A is removed from the fast green dish (step 10), blotted on the second sponge, and placed into the first petri dish of 95-percent ethanol (step 11). The basket should be agitated up and down in the alcohol wash for 4 or 5 seconds to rapidly remove excess stain and prohibit further staining. The basket should remain in step 11 for approximately 1 minute. While basket A is in the first alcohol rinse, basket B is placed into the fast green staining dish (step 10), and basket C is removed from the ethanol storage bath (step 9) and placed into the fast green when basket B is removed. Baskets A, B, and C are moved through the remaining dishes in this manner. About 1 minute in each alcohol rinse (steps 11-13) is satisfactory, but this time can be lengthened without loss of quality. If the sections are not stained dark enough, they can be transferred in the reverse direction through the alcohol sequence and restained in fast green. Sections overstained in fast green cannot be destained.

For temporary slides, the baskets are placed into the A, B, and C storage dishes of 95-percent ethanol (step 14), and sections are trans-

ferred from the baskets to microscope slides.

If permanent slides are to be made, four more steps and six more petri dishes are needed (steps 15-18). The first dish (step 15) contains a 1:1 solution of 95-percent ethanol and parasol or xylene. The remaining dishes (steps 16-18) are filled with parasol or xylene. The baskets should be left in each dish for approximately 1 to 2 minutes. Sections can be temporarily stored up to 1 hour in the last parasol or xylene storage dishes (step 18). Sections left too long in either solution will become brittle and difficult to mount. One gallon of parasol or xylene will be enough for several thousand grafts.

When the sections in the parasol or xylene dishes are found to be understained with fast green, the baskets can be moved backward through the staining sequence until they are placed in fast green dish for additional staining. The sections are then moved forward through the normal sequence and mounted.

Mounting Equipment, Supplies, and Procedures

Materials needed to mount sections are as follows: microscope slides, cover slips, a medium-sized camel's-hair brush, forceps with pointed tips, absorbent tissues, paper towels, and clove oil. Clove oil is needed only for temporary slides and 1 pint will normally make several thousand slides. For making permanent slides the following are needed: Canadian balsam or other synthetic mounting medium, an eyedropper, and slide labels if slides with frosted ends are not used. Lead weights and a warming table or oven are helpful but not necessary.

For temporary slides, several drops of clove oil are spread in a thin layer over the end of the slide where the sections are to be placed. An eyedropper or a camel's-hair brush works well. Baskets containing the unmounted sections are stored in 95-percent ethanol (step 14, fig. 5) while sections are being placed on the slides. A camel's-hair brush or forceps with pointed tips is used to remove one section at a time from the baskets. Each section should be carefully blotted on absorbent tissue or towel and placed on the area of the slide previously covered with clove oil. Four to six sections from each graft are sufficient for each slide, and only one slide is made from each graft. Several drops of clove oil are placed on top of the sections before the coverslip is lowered. Since only one slide is normally prepared from the sections in each compartment, the foil identifying label can be removed from the basket and positioned on the slide so that one corner of the label is under the edge of the coverslip. One end of the coverslip is positioned near the end of the microscope slide and then is slowly lowered until it completely covers the sections. The sections should be totally immersed in clove oil when the coverslip is completely down. If not, several drops of clove oil should be placed on the edge of the coverslip where it will be absorbed into the dry areas. Temporary mounts are then ready to be examined under a microscope for the presence or absence of incompatibility symptoms. One person can section, stain, and mount 75 to 100 temporary slides in an 8-hour day.

Slides should be systematically arranged as they are completed. Temporary slides can be kept for a week or more before viewing, but a daily examination is better. One check of an entire day's work is more efficient than viewing each slide as it is completed.

After the slides have been examined under the microscope and are no longer needed, they should be

stacked in a single layer on a paper towel. When the paper towel is completely covered with slides, another paper towel is put on top of the first layer, and the operation is repeated until all the used slides are stacked. Stacking used microscope slides in single layers between paper towels keeps cleaning to a minimum. When other slides are to be made, the coverslips and sections are wiped from the slides with absorbent tissues, and both slides and coverslips can usually be reused many times without further cleaning. When work has been completed for the year, the slides and coverslips are either washed and stored for the next year or thrown away.

Permanent slides should be made if microscope preparations are to be kept longer than 1 to 2 weeks. New slides and coverslips are generally used when permanent slides are made. Several drops of balsam or synthetic resin are placed on one end of the slide with an eyedropper or small glass rod and spread evenly across the area where sections are to be placed. Sections are removed from the last parasol or xylene dishes (step 18) and carefully blotted on absorbent tissues before being placed on the slide covered with mounting medium. This work must be done quickly because the mounting medium thickens in the outer surface exposed to the air and causes air bubbles to become trapped under the coverslip when it is lowered over the sections. Before the coverslip is lowered, several additional drops of the mounting medium should be placed on top of the sections. The slide becomes messy if too much is used, but the sections dry out and become worthless if too little is applied. Practice will help determine the correct amount. The coverslip must be lowered slowly so that air bubbles are forced out. Gentle pressure on top of the coverslip will force out many bubbles that have been trapped. Additional resin can be placed along the edge of the coverslip if more medium is required. One small corner of the foil identifying label should be under one edge of the coverslip.

After the coverslips have been placed on the sections, the permanent slides are stored on a flat surface to allow the resin to harden. This takes about 24 hours when a 40°C warming table or oven is used. Or the slides can be stored on paper towels on a flat table or bench top and allowed to harden for 4 to 6 days. Small lead weights (57 g) are placed on top of the coverslips when large grafts or thick sections are covered. The lead weights cause the sections to lie flat on the slide so that most areas of the grafts will appear on one plane when viewed through a microscope. Slides should be handled carefully if it is necessary to view them before the resin has hardened. Permanent slides are more difficult to make than temporary slides and fewer can be completed each day. Until a person becomes familiar with the technique, daily production will be only 30 to 50 slides.

The slides can be stored in slide boxes after about 3 days on a warming table or in an oven, but the slides should not be thoroughly cleaned until 1 to 2 weeks later. This interval allows the mounting medium to harden further and prevents coverslips from coming loose during cleaning. Excess mounting medium should be removed from the edges and upper surface of the coverslips with a razor blade or a tissue moistened with parasol or xylene. Care should be taken to prevent cleaning solvent (xylene or parasol) from getting under the coverslip or it will dissolve the mounting medium. Slides should be identified with permanent labels which contain the appropriate scion clone number and rootstock number.

A low power microscope, 20-40 X, is generally best for classifying Douglas-fir grafts as compatible or incompatible. The scope should not have a mechanical stage if temporary slides are to be examined. Wet slides stick to the stage and are difficult to position correctly. Occasionally, magnifications of 100 X or more are needed.

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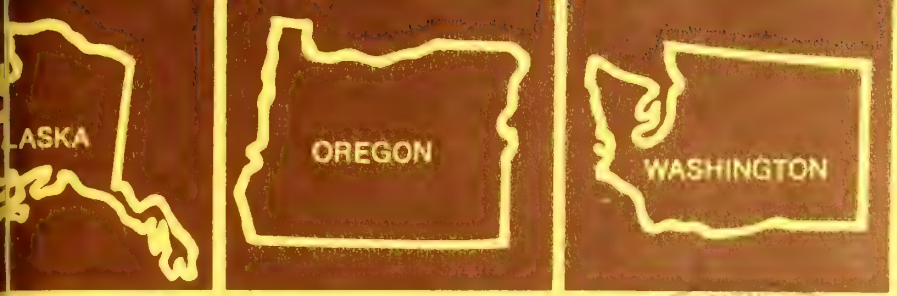

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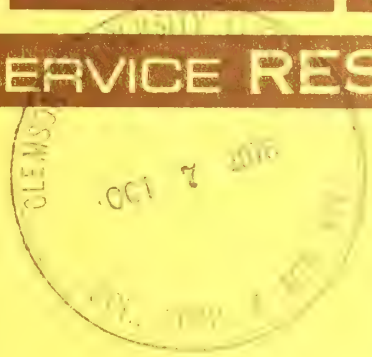

PNW-266

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SOFTWOOD TREE VOLUME EQUATIONS FOR MAJOR CALIFORNIA SPECIES

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ABSTRACT

New cubic-foot, International 1/4-inch board-foot, and Scribner board-foot tree volume equations and tables are presented for eight species: Douglas-fir, Jeffrey pine, ponderosa pine, sugar pine, lodgepole pine, white fir, California red fir, and incense-cedar.

KEYWORDS: Cubic-foot volume tables (stand), board-foot stand volume tables.

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

INTRODUCTION

We have developed, for use in the Forest Survey of California,[1/] new cubic-foot, International 1/4-inch board-foot, and Scribner board-foot tree volume equations for eight conifer species: Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), ponderosa pine (*Pinus ponderosa* Laws.), Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.), sugar pine (*Pinus lambertiana* Dougl.), lodgepole pine (*Pinus contorta* Dougl.), white fir (*Abies concolor* (Gord. & Glend.) Lindl.), California red fir (*Abies magnifica* A. Murr.), and incense-cedar (*Libocedrus decurrens* Torr.).

Previously, Forest Survey has relied on a series of local volume tables (California Forest and Range Experiment Station, Forest Survey 1956) to compile timber volume statistics for California.[2/] These tables assume average heights and form classes by site class based on Forest Survey data collected in the 1940's. The old tables no longer meet Forest Survey needs because (1) we are now interested in an accurate assessment of the volume on individual plots, for which we need volume estimates that take into account individual tree height variation; (2) height over d.b.h. and form class over d.b.h. ratios based on 25-year-old data may not accurately describe today's forest; and (3) the International 1/4-inch board-foot local volume tables assume a top utilization that does not conform with Forest Survey standards.

To replace the old tables, we needed volume equations that would provide comparable estimates of cubic, International 1/4-inch, and Scribner volume to Forest Survey utilization standards. The only existing tables suitable for statewide use (Clements and others 1949a, 1949b) were available only for the Scribner rule and varied by merchantable log height--a variable that is less desirable than total height for use on permanent plots. We therefore chose to develop our own equations.

THE BASIC DATA

Our need was for volume equations suitable for use on trees throughout California. Ideally, for this purpose, we would have preferred a large sample of recently measured trees, drawn from the complete range of forest conditions found in the State. In practice, we were limited to available tree measurement data, since we had neither time nor funds to undertake our own measurements. The most readily available tree measurement data were assembled by Clements and others (1949a, 1949b) during the preparation of their form class volume tables for ponderosa pine, Douglas-fir, white fir, sugar pine, and red fir. The tables themselves are inadequate for our purposes because they are based on log height rather than total height and because they are developed only for the Scribner log rule. However, complete stem profiles are available for all the 2,110 trees used to develop the tables.

1/ A nationwide project of the U.S. Forest Service. The Pacific Northwest Forest and Range Experiment Station conducts the survey in Alaska, California, Hawaii, Oregon, and Washington.

2/ Unpublished cubic and International 1/4-inch rule volume tables on file at the Pacific Northwest Forest and Range Experiment Station.

The felled tree measurements used for the form class volume tables were, for the most part, taken 50-70 years ago. Both young- and old-growth trees were included from a range of sites scattered from the Modoc plateau south along the Sierra Nevada to the Sierra National Forest. To this sample, we added 957 dendrometer-measured trees from recent inventories of the Eldorado and Sierra National Forests. The latter trees included small samples of lodgepole pine and incense cedar--two species not included in the form class volume tables.

Although the size of our sample was more than adequate, the reader should be aware of some important data deficiencies. First, two-thirds of the sample was drawn from trees measured many years ago. While we recognized the danger of bias inherent in the use of old data, that risk seemed preferable to relying on a much smaller sample with a limited geographical distribution. Second, we were unable to find measured-tree data from the Coast Ranges or, more important, for trees under 11.0 inches in diameter breast high. In the case of California red fir, all our sample trees were over 14 inches. This lack of small-tree data posed a particular problem in developing cubic-foot equations, since volumes were needed for all trees 5.0 inches and larger. We were forced to extrapolate, using comparisons of existing tables as a guide to reasonableness. Finally, our sample data for lodgepole pine and incense-cedar were limited--26 trees of the former species and 46 of the latter--and confined to the southern Sierra Nevada. In spite of these scanty data, we decided to develop volume equations for both species, as an alternative preferable to using equations developed for some other species.

DEVELOPING THE EQUATIONS

The STX program (Grosenbaugh 1967) was used to calculate three volumes for each of the sample trees: (1) CV_4--cubic-foot volume to a 4-inch minimum top d.i.b., (2) $IV1/4_{6.5}$--International 1/4-inch board-foot volume to a 6.5-inch minimum top d.i.b., and (3) SV_u--Scribner board-foot volume to a California utilized top as defined by a 1945 Forest Service study (California Forest and Range Experiment Station, Forest Survey 1956). The relationship of the utilized top d.i.b. to d.b.h. is shown in figure 1.

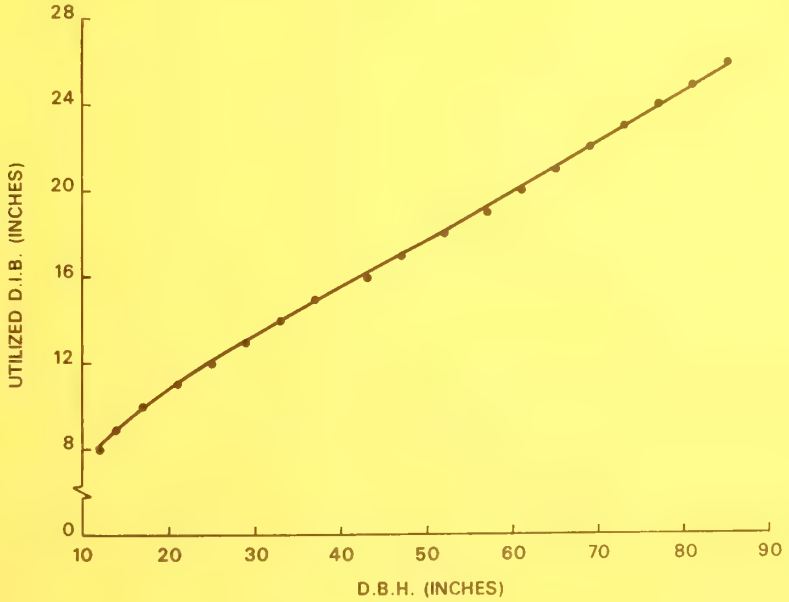

Figure 1.--Relationship of utilized top d.i.b. to d.b.h. (Based on 1945 Forest Service study.)

The method of analysis was essentially that used by Bruce and DeMars (1974). For each species and each log rule, tree volumes were fitted by weighted least squares by means of a stepwise multiple regression analysis. In order to obtain homogeneity of variance, each variable was divided by $0.005454154\ (\text{d.b.h.})^2\ (\text{total height})$--the volume of a cylinder with a basal area and height equal to that of the sample tree. Our choice of independent variables was limited by the information available about the sample trees. Variables tested included d.b.h., total height, their powers, and cross products. Site class and age class (young growth or old growth) were also tried but dropped because their relative contribution to precision was small and their inclusion in the equations would have required the user to obtain site and age information.

The volume equations follow. Where applicable, restraints have been added to insure reasonable extrapolation. The following symbols have been used:

V = volume
D = diameter breast high
H = total height
F = form factor (the ratio of a tree's volume to that of a cylinder of the same diameter and height)
CF_4 = cubic-foot form factor
$IF1/4_{6.5}$ = International 1/4-inch board-foot form factor to a 6.5-inch top d.i.b.
SF_u = Scribner form factor (16-foot logs) to a California utilized top.[3/]

To determine the volume of a given tree, first calculate the tree form factor, (transformed volume) using the appropriate equation for the species. Then multiply the form factor by the volume of a cylinder with the same height and basal area as the tree. Thus: $V = 0.005454154\ D^2H\ F$, where F is equal to the form factor appropriate for the species and log rule. The form factor equations are:

Species	Equation
Douglas-fir	CF_4[4/] $= 0.248569 + 0.0253524\ (\frac{H}{D}) - 0.0000560175\ (\frac{H^2}{D})$
	$IF1/4_{6.5}$ (when $H \geq 57$ feet) $= 1.575350 - 1269.84\ (\frac{1}{DH}) + 20.4816\ (\frac{1}{D}) + 0.0000135387\ H^2$

[3/] See figure 1.

[4/] For all species except incense-cedar, CF_4 will be set equal to 0.4 whenever the equation value is higher than 0.4. When the equation value for CF_4 is lower than 0.3, it is set equal to 0.3. This will insure reasonable extrapolation beyond the limits of the study data.

Douglas-fir

$$IF1/4_{6.5} = 1.75550 - 1.00000 \left(\frac{1}{H}\right) + 20.4816 \left(\frac{1}{D}\right) + 0.0000135387\ H^2 + 1858.80 \left(\frac{1}{DH}\right) - 119.410 \left(\frac{1}{D}\right)$$

$$SF_u = 2.58530 - 83.5000 \left(\frac{1}{H}\right)$$

Ponderosa and Jeffrey pine

$$CF_4 = 0.402060 - 0.899914 \left(\frac{1}{D}\right)$$

$$IF1/4_{6.5} = 3.02027 - 22.0313 \left(\frac{1}{D}\right) + 0.00201362\ (H)$$

$$SF_u \text{ [5/]} = 3.22940 - 585.500 \left(\frac{1}{DH}\right) - 21.7575 \left(\frac{1}{D}\right)$$

Sugar pine

$$CF_4 = 0.358550 - 0.488134 \left(\frac{1}{D}\right)$$

$$IF1/4_{6.5} = 2.75889 - 18.1229 \left(\frac{1}{D}\right) + 0.000225065 \left(\frac{H^2}{D}\right)$$

$$SF_u = 2.88706 - 25.2838 \left(\frac{1}{D}\right)$$

Lodgepole pine

$$CF_4 = 0.422709 - 0.0000612236 \left(\frac{H^2}{D}\right)$$

$$IF1/4_{6.5} = 2.86258 - 716.659 \left(\frac{1}{DH}\right)$$

$$SF_u = 2.63048 - 850.630 \left(\frac{1}{DH}\right)$$

White fir

$$CF_4 = 0.299039 - 1.91272 \left(\frac{1}{H}\right) + 0.000367217 \left(\frac{H^2}{D}\right)$$

$$IF1/4_{6.5} \text{ (when } D \geq 11.0 \text{ inches)} = 2.08637 - 119.839 \left(\frac{1}{D^2}\right) + 0.000620285 \left(\frac{H^2}{D}\right)$$

$$IF1/4_{6.5} \text{ (when } D < 11.0 \text{ inches)} = (0.45 + 0.05\ D)\ (1.09597 + 0.000056389\ H^2)$$

$$SF_u = 2.31733 - 16.9592 \left(\frac{1}{D}\right) + 0.000548156 \left(\frac{H^2}{D}\right)$$

[5/] SF_u will be set equal to 0.7 whenever it drops below this value to insure reasonable extrapolation from small trees. The volume of a tree with a minimum saw log diameter of 8 inches/inside bark by 12 feet long is 23 board feet.

California red fir

$$CF_4 = 0.231237 + 0.028176 \left(\frac{H}{D}\right)$$

$$IF1/4_{6.5} = 1.54320 + 0.00133466 \left(\frac{H^2}{D}\right)$$

$$SF_u = 1.59669 - 464.752 \left(\frac{1}{DH}\right) + 0.00105105 \left(\frac{H^2}{D}\right)$$

Incense-cedar

$$CF_4 \text{ [6/]} = 0.225786 + 4.44236 \left(\frac{1}{H}\right)$$

$$IF1/4_{6.5} = 1.39269 + 0.0000259631 H^2$$

$$SF_u = 1.82080 - 11.7184 \left(\frac{1}{D}\right)$$

Volumes calculated from these equations are in tables 1-21.

RELIABILITY OF THE EQUATIONS

One measure of the reliability of an equation is the extent to which the individual observations deviate from the regression surfaces. A measure of this residual variation is the root mean squared error--the square root of the mean squared difference between the predicted and actual values. Table 22 shows the root mean squared error of each form factor equation, expressed both in absolute terms and as a percent of the average form factor.

It is generally desirable to test new equations against an independent source of data--data not used in the construction of the equations. We tested the equations on 441 trees from the Stanislaus National Forest which had been measured with an optical dendrometer. The results of this test, together with the results of a test of the old Forest Survey local volume tables, appear in table 23. Figures 2-9 illustrate the relationship between estimated and actual volume of the test trees. As expected, the new equations, based on d.b.h. and total height, account for more of the variation in individual tree volume than do the old tables based on d.b.h. alone. The old lodgepole pine and incense-cedar tables gave very biased estimates of tree volume in this test. Tests against different trees in other geographic areas might well produce different biases. However, the new equations, which reflect differences in individual tree heights, should carry less risk of bias than the old tables, which rely on assumptions about the average relationships between heights and d.b.h. within a site class.

We also developed a complete set of volume equations which used Girard form class as one of the independent variables. When individual tree, Girard form class is known without error, these equations are more precise than the ones presented here. In practice, however, actual form class is seldom known. A common procedure is to use average form classes by species and sometimes by diameter class. We wondered whether the addition of form class would improve the estimate of individual tree volume when average form class was substituted for actual form class.

6/ When the equation value for CF_4 is < 0.27, it is set equal to 0.27 to insure reasonable extrapolation.

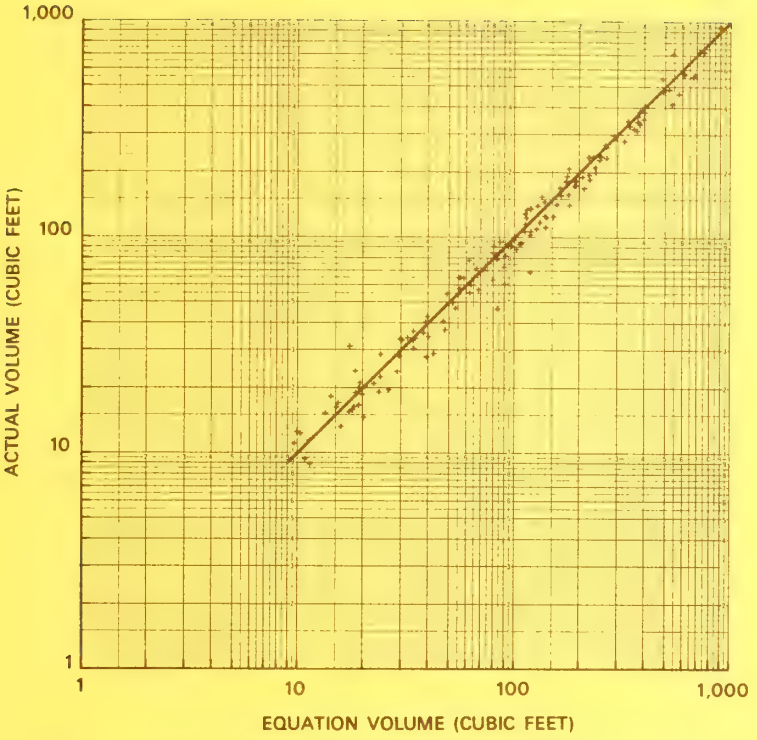

Figure 2.--Relationship between the measured cubic-foot volume of 146 ponderosa and Jeffrey pine trees and estimates from the new equation.

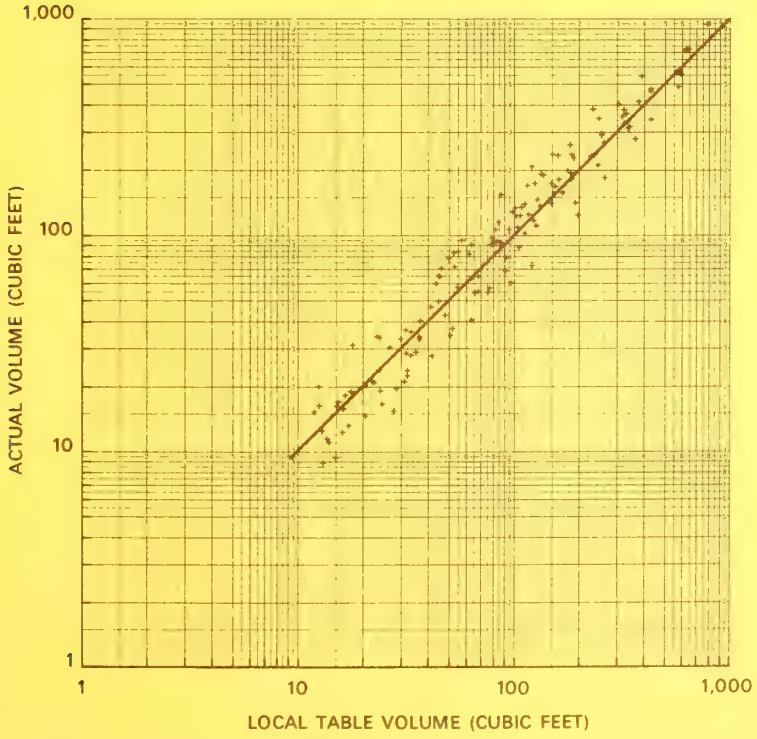

Figure 3.--Relationship between the measured cubic-foot volume of 146 ponderosa and Jeffrey pine trees and estimates from Forest Survey local volume tables.

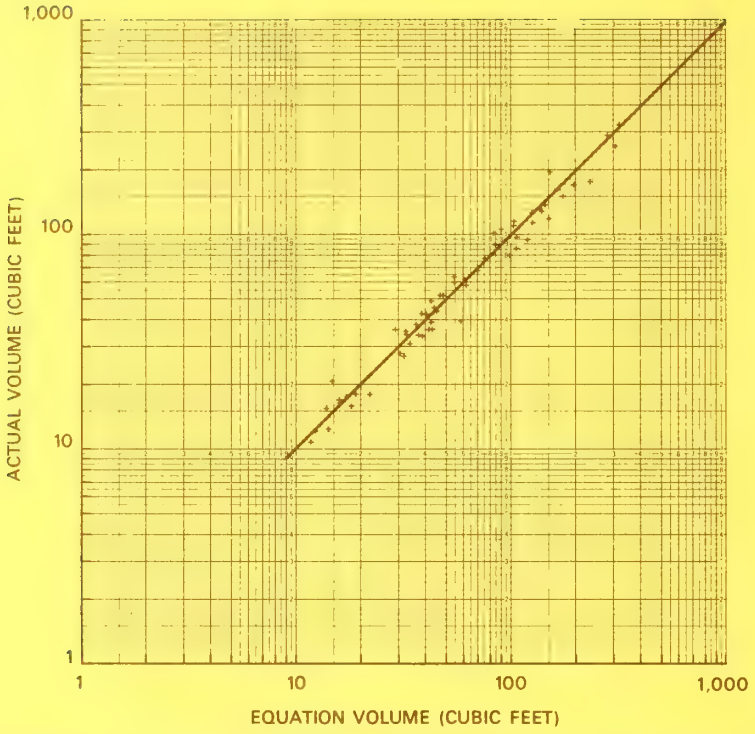

Figure 4.--Relationship between the measured cubic-foot volume of 60 lodgepole pine trees and estimated volume from the new equation.

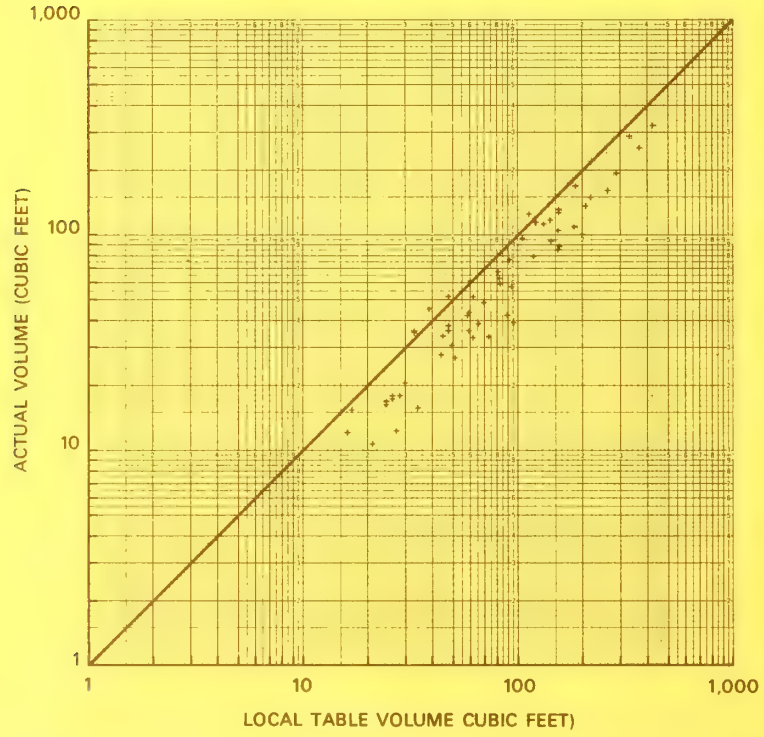

Figure 5.--Relationship between the measured cubic-foot volume of 60 lodgepole pine trees and estimates from the Forest Survey local volume tables.

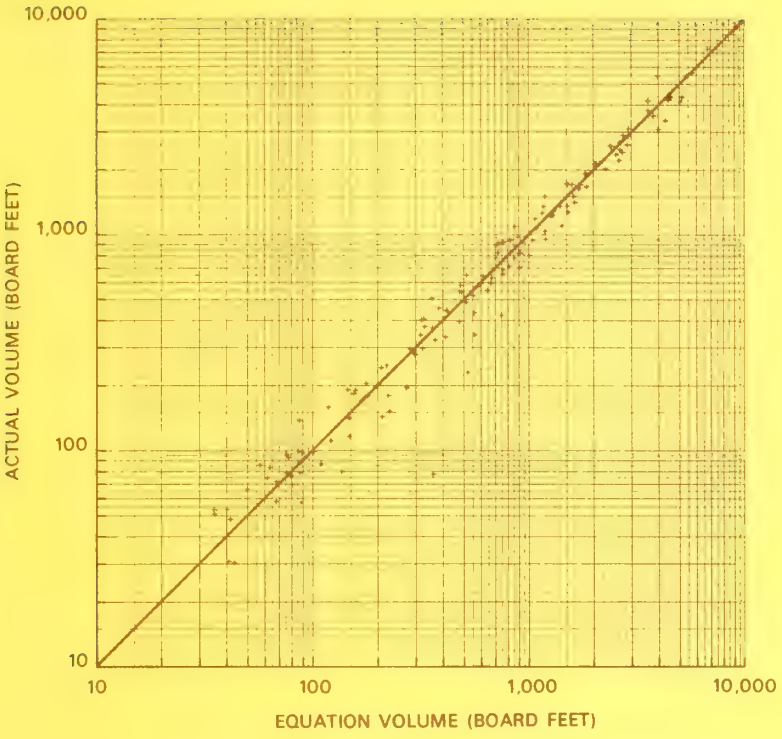

Figure 6.--Relationship between the measured International 1/4-inch board-foot volume of 146 ponderosa and Jeffrey pine trees and estimates from the new equation.

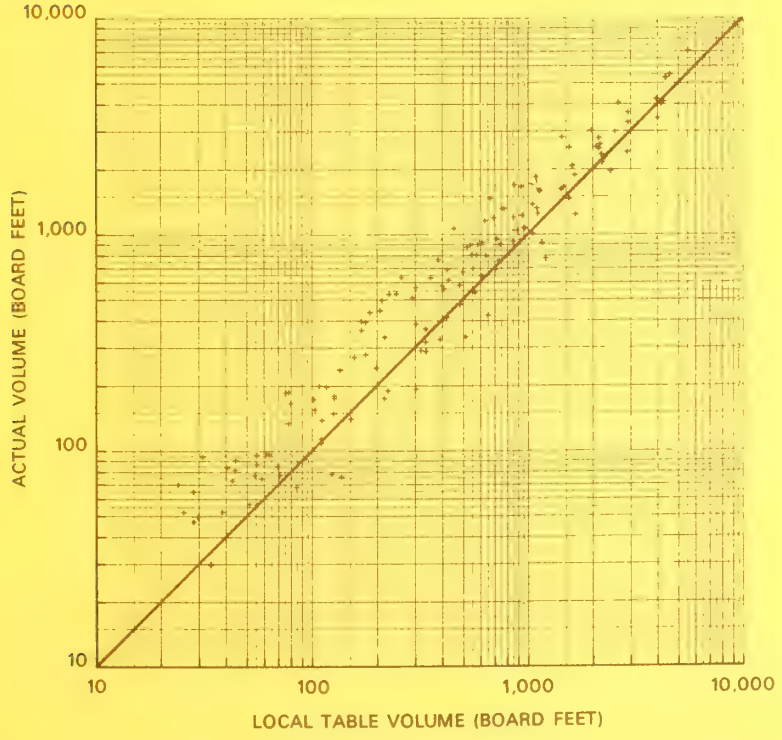

Figure 7.--Relationship between the measured International 1/4-inch board-foot volume of 146 ponderosa and Jeffrey pine trees and estimates from the Forest Survey local volume tables.

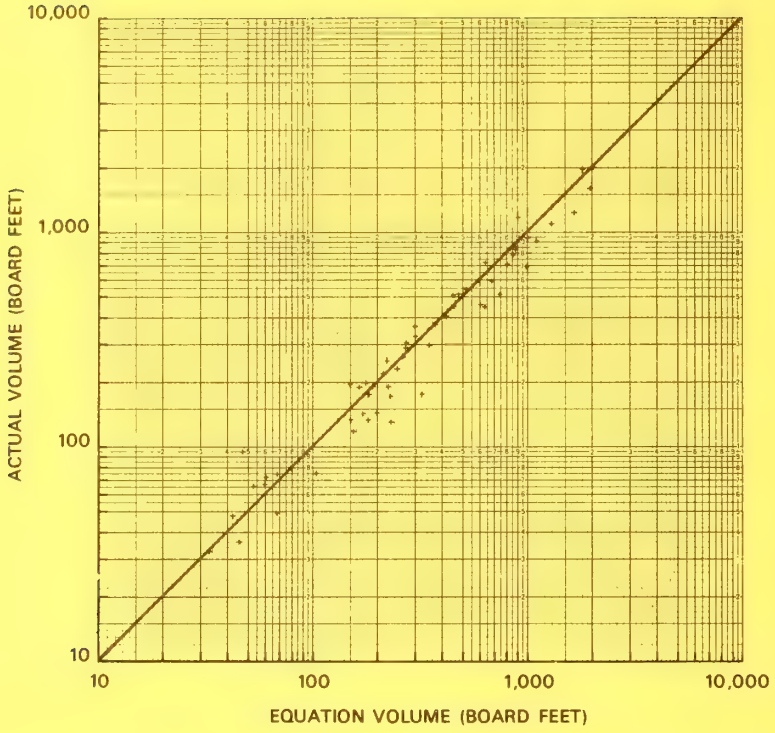

Figure 8.--Relationship between the measured International 1/4-inch board-foot volume of 60 lodgepole pine trees and estimates from the new equation.

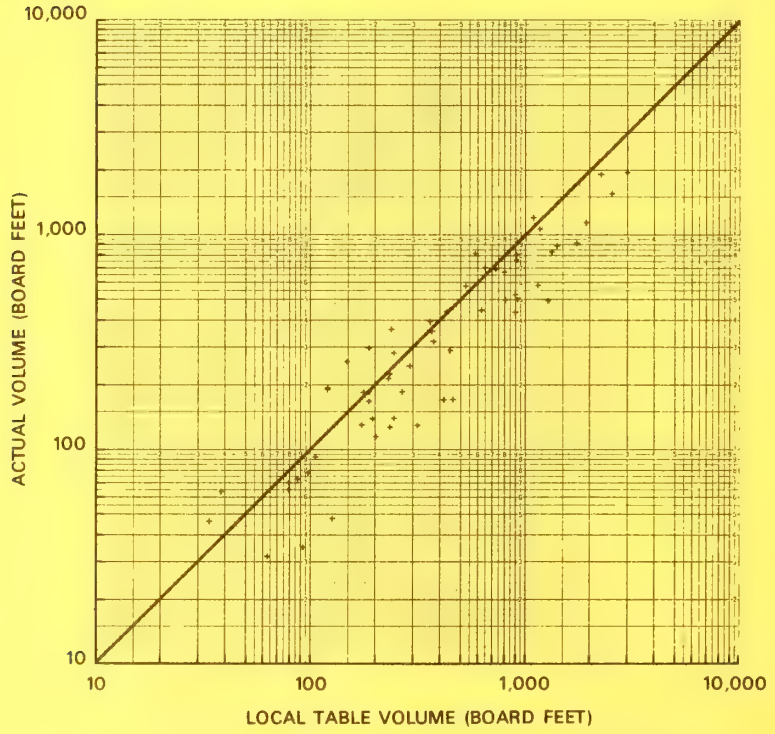

Figure 9.--Relationship between the measured International 1/4-inch board-foot volume of 60 lodgepole pine trees and estimates from the Forest Survey local volume tables.

To answer this question, we tested equations with and without form class against our 441 Stanislaus National Forest trees. The results of this test are in table 24. In this test, the extra precision gained by adding a form class variable was lost completely when average form class was substituted for actual form class, even though the actual average form classes of the test trees were used. We therefore decided not to include the form class equations in this note. We will be glad to supply the form class equations on request. However, we do not recommend their use unless form class is known for every tree.

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Table 1.—Cubic-foot volume of Douglas-fir

Stump and top excluded

Top diameter, 4 inches
Stump height, 1 foot

Diameter breast height outside bark--inches[1/]	Total height--Feet																				
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
6	3	4	5	5	6	7	8	9	9	10	11	12	13								
8	5	7	8	10	11	13	14	15	17	18	20	21	22								
10	7	10	12	15	17	20	22	24	26	28	31	33	35								
12	10	13	17	21	24	28	31	35	38	41	44	47	50								
14	13	18	22	27	31	36	42	47	51	56	60	64	68								
16	17	22	28	33	39	46	52	58	65	72	78	84	89								
18	21	27	34	41	48	56	63	71	79	87	95	103	111								
20	26	33	41	49	58	67	76	85	94	104	113	123	133	142	152	161					
22	32	40	49	59	69	79	89	100	111	122	133	144	155	166	177	188					
24	38	47	57	68	80	92	104	116	129	141	154	167	180	193	205	218					
26	44	55	66	79	92	106	120	134	148	162	177	192	206	221	235	249					
28		64	77	90	105	121	136	152	169	185	201	218	234	251	267	283					
30		74	88	103	119	137	154	172	190	209	227	245	264	282	301	319	337	354	372	389	405
32		84	101	117	134	154	173	193	213	234	254	275	295	316	336	356	376	396	415	434	453
34			113	132	151	172	193	215	236	260	283	306	329	351	374	396	418	440	462	483	503
36			127	148	170	191	214	239	264	288	313	338	364	389	413	438	463	487	510	534	556
38				165	189	213	237	263	291	318	345	373	400	428	455	482	509	535	561	587	612
40				183	209	236	262	289	319	349	379	409	439	469	498	528	557	586	615	643	670
42				202	231	260	289	317	348	381	413	446	479	511	544	576	608	639	671	701	731
44				222	253	285	317	348	380	414	450	485	521	556	591	626	661	695	729	762	795
46				242	277	312	346	381	415	450	488	526	564	602	640	678	716	753	789	825	861
48				264	302	339	377	415	452	490	528	568	610	651	692	733	773	813	852	891	929
50				286	327	368	409	450	491	532	573	614	657	701	745	789	832	875	918	959	1,000
52						398	442	487	531	575	619	664	708	753	800	847	894	940	985	1,030	1,074
54						429	477	525	573	620	668	716	763	811	859	908	957	1,007	1,055	1,104	1,151
56						462	513	564	616	667	718	770	821	872	924	975	1,026	1,078	1,129	1,180	1,232
58						495	550	605	661	716	771	826	881	936	991	1,046	1,101	1,156	1,211	1,266	1,321
60						530	589	648	707	766	825	884	942	1,001	1,060	1,119	1,178	1,237	1,296	1,355	1,414
62									755	818	881	943	1,006	1,069	1,132	1,195	1,258	1,321	1,384	1,447	1,510
64									804	871	938	1,005	1,072	1,139	1,206	1,273	1,340	1,407	1,474	1,541	1,608
66									855	927	998	1,069	1,140	1,212	1,283	1,354	1,425	1,497	1,568	1,639	1,711
68									908	984	1,059	1,135	1,211	1,286	1,362	1,438	1,513	1,589	1,665	1,740	1,816
70									962	1,042	1,122	1,203	1,283	1,363	1,443	1,523	1,604	1,684	1,764	1,844	1,924
72											1,188	1,272	1,357	1,442	1,527	1,612	1,696	1,781	1,866	1,951	2,036
74											1,254	1,344	1,434	1,523	1,613	1,702	1,792	1,882	1,971	2,061	2,150
76											1,323	1,418	1,512	1,607	1,701	1,796	1,890	1,985	2,079	2,174	2,268
78											1,394	1,493	1,593	1,692	1,792	1,891	1,991	2,091	2,190	2,290	2,389
80											1,466	1,571	1,676	1,780	1,885	1,990	2,094	2,199	2,304	2,409	2,313

[1/] Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.

NOTE.--Block indicates extent of data.

Table 2.—Board-foot volume of Douglas-fir by International 1/4-inch rule

Stump and top excluded

Top diameter, 6.5 inches
Stump height, 1 foot

Diameter breast height outside bark--inches[1/]	Total height--Feet																				
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
10	22	35	51	72	93	114	136	158	181	204	228	252	277								
12	33	52	74	101	129	157	185	215	245	275	307	339	373								
14	46	72	101	135	170	206	242	280	318	357	397	439	482								
16	62	96	132	175	218	262	307	353	400	449	499	551	605								
18	81	123	168	219	271	324	379	435	492	551	612	675	740								
20	102	154	208	269	330	393	458	525	593	664	736	812	890	971	1,055	1,142					
22	127	188	252	323	395	469	545	623	703	786	872	961	1,053	1,148	1,247	1,350					
24	154	226	301	382	466	551	639	730	823	919	1,019	1,122	1,229	1,340	1,455	1,575					
26	184	267	353	447	543	640	741	845	952	1,062	1,177	1,295	1,418	1,546	1,679	1,818					
28		312	410	516	625	736	850	968	1,090	1,216	1,346	1,481	1,621	1,767	1,919	2,077					
30		360	472	591	713	838	967	1,100	1,237	1,379	1,526	1,679	1,838	2,003	2,175	2,354	2,541	2,735	2,938	3,150	3,371
32		411	537	670	807	947	1,091	1,240	1,394	1,553	1,718	1,890	2,068	2,253	2,447	2,648	2,858	3,077	3,306	3,544	3,793
34			607	755	907	1,063	1,223	1,389	1,560	1,737	1,921	2,112	2,311	2,518	2,734	2,959	3,194	3,439	3,694	3,961	4,240
36			681	844	1,012	1,185	1,362	1,545	1,735	1,931	2,135	2,347	2,568	2,798	3,037	3,287	3,548	3,820	4,104	4,401	4,711
38				939	1,124	1,313	1,509	1,710	1,919	2,136	2,361	2,595	2,838	3,092	3,356	3,632	3,920	4,221	4,536	4,864	5,207
40				1,039	1,241	1,449	1,663	1,884	2,113	2,351	2,597	2,854	3,121	3,400	3,691	3,994	4,311	4,642	4,989	5,350	5,728
42				1,143	1,364	1,590	1,824	2,066	2,316	2,576	2,845	3,126	3,418	3,723	4,041	4,374	4,721	5,084	5,463	5,859	6,273
44				1,253	1,492	1,739	1,993	2,256	2,528	2,811	3,105	3,410	3,729	4,061	4,408	4,770	5,149	5,545	5,958	6,391	6,843
46				1,367	1,627	1,894	2,170	2,455	2,750	3,056	3,375	3,707	4,053	4,413	4,790	5,184	5,595	6,026	6,476	6,946	7,438
48				1,487	1,767	2,056	2,354	2,661	2,981	3,312	3,657	4,016	4,390	4,780	5,188	5,615	6,060	6,526	7,014	7,524	8,058
50				1,612	1,914	2,224	2,545	2,877	3,221	3,578	3,950	4,337	4,740	5,162	5,602	6,062	6,544	7,047	7,574	8,125	8,702
52						2,399	2,744	3,100	3,470	3,854	4,254	4,670	5,104	5,558	6,032	6,527	7,046	7,588	8,155	8,749	9,370
54						2,581	2,950	3,332	3,729	4,140	4,569	5,016	5,482	5,969	6,477	7,009	7,566	8,148	8,758	9,396	10,064
56						2,769	3,164	3,572	3,996	4,437	4,896	5,374	5,873	6,394	6,939	7,509	8,105	8,729	9,382	10,066	10,782
58						2,964	3,385	3,821	4,274	4,744	5,234	5,744	6,277	6,834	7,416	8,025	8,662	9,329	10,028	10,759	11,524
60						3,165	3,614	4,078	4,560	5,061	5,583	6,127	6,695	7,288	7,909	8,558	9,238	9,950	10,695	11,475	12,292
62									4,856	5,388	5,943	6,522	7,126	7,757	8,418	9,109	9,832	10,590	11,383	12,214	13,084
64									5,161	5,726	6,315	6,929	7,571	8,241	8,942	9,676	10,445	11,250	12,093	12,976	13,900
66									5,475	6,074	6,698	7,349	8,028	8,739	9,483	10,261	11,076	11,930	12,824	13,761	14,742
68									5,798	6,432	7,092	7,780	8,500	9,252	10,039	10,863	11,726	12,630	13,577	14,569	15,608
70									6,131	6,800	7,497	8,225	8,985	9,779	10,611	11,482	12,394	13,350	14,351	15,399	16,498
72											7,914	8,681	9,483	10,321	11,199	12,118	13,081	14,089	15,146	16,253	17,414
74											8,341	9,150	9,995	10,878	11,803	12,771	13,786	14,849	15,963	17,130	18,354
76											8,781	9,631	10,520	11,449	12,422	13,442	14,509	15,628	16,801	18,030	19,318
78											9,231	10,124	11,058	12,035	13,058	14,129	15,251	16,428	17,661	18,953	20,308
80											9,692	10,630	11,610	12,635	13,709	14,834	16,012	17,247	18,542	19,899	21,321

[1/] Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.

NOTE.--Block indicates extent of data.

Table 3.—Board-foot volume of Douglas-fir by Scribner rule in 16-foot logs to a utilized top

Stump and top excluded

Top diameter, variable
Stump height, 1 foot

Diameter breast height outside bark--inches[1]	Total height--Feet																				
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
12	[2]23	36	56	77	97	117	137	158	178	198	219	239	259								
14	23	49	77	104	132	159	187	215	242	270	298	325	353								
16	28	64	100	136	172	208	244	280	317	353	389	425	461								
18	35	81	127	172	218	264	309	355	401	446	492	538	583								
20	43	100	156	213	269	325	382	438	495	551	607	664	720	777	833	889					
22	53	121	189	257	326	394	462	530	599	667	735	803	872	940	1,008	1,076					
24	63	144	225	306	387	469	550	631	712	794	875	956	1,037	1,118	1,200	1,281					
26	73	169	264	359	455	550	645	741	836	931	1,027	1,122	1,217	1,313	1,408	1,503					
28		196	306	417	527	638	748	859	970	1,080	1,191	1,301	1,412	1,522	1,633	1,743					
30		225	352	478	605	732	859	986	1,113	1,240	1,367	1,494	1,621	1,748	1,874	2,001	2,128	2,255	2,382	2,509	2,636
32		256	400	544	689	833	978	1,122	1,266	1,411	1,555	1,700	1,844	1,988	2,133	2,277	2,421	2,566	2,710	2,855	2,999
34			452	615	778	941	1,104	1,267	1,430	1,593	1,756	1,919	2,082	2,245	2,408	2,571	2,734	2,897	3,060	3,223	3,386
36			406	689	872	1,054	1,237	1,420	1,603	1,785	1,968	2,151	2,334	2,516	2,699	2,882	3,065	3,247	3,430	3,613	3,796
38				768	971	1,175	1,379	1,582	1,786	1,989	2,193	2,397	2,600	2,804	3,007	3,211	3,415	3,618	3,822	4,025	4,229
40				851	1,076	1,302	1,527	1,753	1,979	2,204	2,430	2,655	2,881	3,107	3,332	3,558	3,784	4,009	4,235	4,460	4,686
42				938	1,187	1,435	1,684	1,933	2,181	2,430	2,679	2,928	3,176	3,425	3,674	3,923	4,171	4,420	4,669	4,918	5,166
44				1,029	1,302	1,575	1,848	2,121	2,394	2,667	2,940	3,213	3,486	3,759	4,032	4,305	4,578	4,851	5,124	5,397	5,670
46				1,125	1,423	1,722	2,020	2,318	2,617	2,915	3,213	3,512	3,810	4,109	4,407	4,705	5,004	5,302	5,600	5,899	6,197
48				1,225	1,550	1,875	2,199	2,524	2,849	3,174	3,499	3,824	4,149	4,474	4,799	5,123	5,448	5,773	6,098	6,423	6,748
50				1,329	1,682	2,034	2,387	2,739	3,092	3,444	3,797	4,149	4,502	4,854	5,207	5,559	5,912	6,264	6,617	6,969	7,322
52						2,200	2,581	2,963	3,344	3,725	4,106	4,488	4,869	5,250	5,632	6,013	6,394	6,775	7,157	7,538	7,919
54						2,373	2,784	3,195	3,606	4,017	4,428	4,840	5,251	5,662	6,073	6,484	6,895	7,307	7,718	8,129	8,540
56						2,552	2,994	3,436	3,878	4,320	4,763	5,205	5,647	6,089	6,531	6,974	7,416	7,858	8,300	8,742	9,184
58						2,737	3,211	3,686	4,160	4,634	5,109	5,583	6,057	6,532	7,006	7,481	7,955	8,429	8,904	9,378	9,852
60						2,929	3,437	3,944	4,452	4,960	5,467	5,975	6,482	6,990	7,498	8,005	8,513	9,021	9,528	10,036	10,543
62									4,754	5,296	5,838	6,380	6,922	7,464	8,006	8,548	9,090	9,632	10,174	10,716	11,258
64									5,065	5,643	6,220	6,798	7,376	7,953	8,531	9,108	9,686	10,263	10,841	11,419	11,996
66									5,387	6,001	6,615	7,230	7,844	8,458	9,072	9,686	10,301	10,915	11,529	12,143	12,758
68									5,718	6,370	7,022	7,674	8,326	8,978	9,630	10,282	10,934	11,586	12,238	12,890	13,542
70									6,060	6,751	7,441	8,132	8,823	9,514	10,205	10,896	11,587	12,278	12,969	13,660	14,351
72											7,873	8,604	9,335	10,066	10,797	11,528	12,259	12,990	13,721	14,452	15,183
74											8,316	9,088	9,861	10,633	11,405	12,177	12,949	13,721	14,493	15,266	16,038
76											8,772	9,586	10,401	11,215	12,030	12,844	13,659	14,473	15,287	16,102	16,916
78											9,240	10,097	10,955	11,813	12,671	13,529	14,387	15,245	16,103	16,960	17,818
80											9,719	10,622	11,524	12,427	13,329	14,232	15,134	16,037	16,939	17,841	18,744

[1] Diameter classes are midpoint; e.g. 12-inch class includes 11.0-12.9.
NOTE.--Block indicates extent of data.

[2] The volume of a tree with a minimum saw log 8 inches d.i.b. and 12 feet long is 23 board feet. Trees lacking this minimum saw log have no Scribner volume.

Table 4.—Cubic-foot volume of ponderosa and Jeffrey pine

Stump and top excluded

Top diameter, 4 inches
Stump height, 1 foot

Diameter breast height outside bark--inches[1/]	Total height--Feet																				
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
6	2	3	4	4	5	5	6	6	7	8	8	9	9								
8	4	5	6	7	8	9	10	12	13	14	15	16	17								
10	7	9	10	12	14	15	17	19	20	22	24	26	27								
12	10	13	15	18	21	23	26	28	31	33	36	39	41								
14	14	18	22	25	29	32	36	40	43	47	51	54	58								
16	19	24	29	34	39	43	48	53	58	63	68	72	77								
18	25	31	37	44	50	56	62	68	75	81	87	93	100								
20	31	39	47	55	62	70	78	86	93	101	109	117	125	132	140	148					
22	38	48	57	67	76	86	95	105	114	124	133	143	153	162	172	181					
24	46	57	69	80	92	103	115	126	137	149	160	172	183	195	206	218					
26	54	68	81	95	108	122	135	149	163	176	190	203	217	230	244	257					
28		79	95	111	127	142	158	174	190	206	221	237	253	269	285	301					
30		91	110	128	146	164	183	201	219	237	256	274	292	310	329	347	365	384	402	420	438
32		104	125	146	167	188	209	230	251	272	292	313	334	355	376	397	418	439	459	480	501
34			142	166	189	213	237	260	284	308	332	355	379	403	426	450	474	497	521	545	568
36			160	187	213	240	267	293	320	346	373	400	426	453	480	506	533	560	586	613	640
38				209	238	268	298	328	358	387	417	447	477	507	536	566	596	626	656	685	715
40				232	265	298	331	364	397	431	464	497	530	563	596	629	662	696	729	762	795
42				256	293	330	366	403	439	476	513	549	586	623	659	696	732	769	806	842	879
44				282	322	363	403	443	484	524	564	604	645	685	725	766	806	846	887	927	967
46				309	353	397	441	486	530	574	618	662	706	750	795	839	883	927	971	1,015	1,059
48				337	385	434	482	530	578	626	674	723	771	819	867	915	963	1,012	1,060	1,108	1,156
50				367	419	471	524	576	628	681	733	786	838	890	943	995	1,047	1,100	1,152	1,204	1,257
52						511	567	624	681	738	794	851	908	965	1,021	1,078	1,135	1,192	1,248	1,305	1,362
54						552	613	674	736	797	858	919	981	1,042	1,103	1,165	1,226	1,287	1,348	1,410	1,471
56						594	660	726	792	858	924	990	1,056	1,122	1,188	1,254	1,320	1,386	1,452	1,518	1,585
58						638	709	780	851	922	993	1,064	1,135	1,206	1,277	1,348	1,418	1,489	1,560	1,631	1,702
60						684	760	836	912	988	1,064	1,140	1,216	1,292	1,368	1,444	1,520	1,596	1,672	1,748	1,824
62									975	1,056	1,138	1,219	1,300	1,381	1,463	1,544	1,625	1,706	1,788	1,869	1,950
64									1,040	1,127	1,214	1,300	1,387	1,474	1,560	1,647	1,734	1,820	1,907	1,994	2,080
66									1,107	1,200	1,292	1,384	1,477	1,569	1,661	1,753	1,846	1,938	2,030	2,123	2,215
68									1,177	1,275	1,373	1,471	1,569	1,667	1,765	1,863	1,961	2,059	2,157	2,255	2,354
70									1,248	1,352	1,456	1,560	1,664	1,768	1,872	1,976	2,080	2,184	2,288	2,392	2,496
72											1,542	1,652	1,762	1,873	1,983	2,093	2,203	2,313	2,423	2,533	2,644
74											1,630	1,747	1,863	1,980	2,096	2,213	2,329	2,446	2,562	2,678	2,795
76											1,721	1,844	1,967	2,090	2,213	2,336	2,459	2,582	2,705	2,827	2,950
78											1,814	1,944	2,073	2,203	2,333	2,462	2,592	2,721	2,851	2,981	3,110
80											1,910	2,046	2,183	2,319	2,456	2,592	2,728	2,865	3,001	3,138	3,274

[1/] Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.

NOTE.--Block indicates extent of data.

Table 5.—Board-foot volume of ponderosa and Jeffrey pine by International 1/4-inch rule

Stump and top excluded

Top diameter, 6.5 inches
Stump height, 1 foot

Diameter breast height outside bark--inches[1/]	Total height--Feet																				
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
10	20	25	31	37	43	49	56	62	69	76	84	92	99								
12	40	50	62	73	85	97	109	121	134	148	161	175	189								
14	65	83	101	119	137	157	176	196	217	237	259	280	303								
16	96	122	148	174	202	229	258	286	316	346	376	407	439								
18	133	168	203	240	277	315	353	392	432	473	514	556	599								
20	174	220	267	315	363	412	463	514	566	618	672	727	782	839	896	954					
22	222	280	339	399	460	523	586	651	716	783	850	919	989	1,060	1,132	1,204					
24	274	346	419	493	569	646	724	803	884	966	1,049	1,133	1,219	1,306	1,394	1,483					
26	332	419	507	597	688	781	875	971	1,068	1,167	1,267	1,369	1,472	1,577	1,683	1,790					
28		499	604	711	819	929	1,041	1,155	1,270	1,387	1,506	1,626	1,748	1,872	1,998	2,125					
30		586	709	834	961	1,090	1,221	1,354	1,489	1,626	1,765	1,906	2,048	2,193	2,340	2,489	2,640	2,792	2,947	3,104	3,262
32		679	822	967	1,114	1,263	1,415	1,569	1,725	1,883	2,044	2,207	2,372	2,539	2,709	2,880	3,054	3,231	3,409	3,590	3,773
34			943	1,109	1,278	1,449	1,623	1,799	1,978	2,159	2,343	2,529	2,718	2,910	3,104	3,300	3,499	3,701	3,905	4,112	4,321
36			1,073	1,261	1,453	1,647	1,845	2,045	2,248	2,454	2,662	2,874	3,088	3,305	3,525	3,748	3,974	4,203	4,434	4,668	4,905
38				1,423	1,639	1,858	2,081	2,306	2,535	3,767	3,002	3,240	3,481	3,726	3,974	4,224	4,479	4,736	4,996	5,260	5,526
40				1,595	1,836	2,082	2,331	2,583	2,839	3,099	3,361	3,628	3,898	4,171	4,448	4,729	5,013	5,301	5,592	5,886	6,184
42				1,776	2,045	2,318	2,595	2,876	3,160	3,449	3,741	4,038	4,338	4,642	4,950	5,262	5,577	5,897	6,220	6,548	6,879
44				1,967	2,264	2,567	2,873	3,184	3,499	3,818	4,141	4,469	4,801	5,137	5,478	5,822	6,171	6,525	6,882	7,244	7,610
46				2,167	2,495	2,828	3,165	3,507	3,854	4,206	4,562	4,922	5,288	5,658	6,032	6,412	6,795	7,184	7,577	7,975	8,378
48				2,377	2,737	3,102	3,472	3,847	4,227	4,612	5,002	5,397	5,798	6,203	6,613	7,029	7,449	7,875	8,306	8,741	9,182
50				2,597	2,990	3,388	3,792	4,201	4,616	5,037	5,463	5,894	6,331	6,773	7,221	7,674	8,133	8,597	9,067	9,543	10,023
52						3,687	4,126	4,572	5,023	5,480	5,943	6,412	6,887	7,368	7,855	8,348	8,847	9,352	9,862	10,379	10,901
54						3,999	4,475	4,958	5,447	5,942	6,444	6,953	7,467	7,988	8,516	9,050	9,590	10,137	10,690	11,250	11,816
56						4,323	4,837	5,359	5,888	6,423	6,965	7,514	8,071	8,634	9,203	9,780	10,364	10,954	11,552	12,156	12,767
58						4,659	5,214	5,776	6,346	6,922	7,507	8,095	8,697	9,304	9,917	10,538	11,167	11,803	12,446	13,097	13,755
60						5,009	5,605	6,209	6,821	7,440	8,068	8,704	9,347	9,998	10,658	11,325	12,000	12,683	13,374	14,073	14,780
62									7,313	7,977	8,650	9,331	10,020	10,718	11,425	12,140	12,863	13,595	14,335	15,084	15,841
64									7,822	8,532	9,251	9,980	10,717	11,463	12,218	12,983	13,756	14,538	15,330	16,130	16,939
66									8,348	9,106	9,873	10,650	11,437	12,233	13,039	13,854	14,679	15,513	16,357	17,211	18,074
68									8,891	9,698	20,515	11,343	12,180	13,028	13,885	14,753	15,631	16,520	17,418	18,326	19,245
70									9,452	10,309	11,178	12,057	12,947	13,847	14,759	15,681	16,614	17,558	18,512	19,477	20,453
72											11,860	12,793	13,737	14,692	15,659	16,637	17,626	18,627	19,639	20,663	21,698
74											12,563	13,550	14,550	15,561	16,585	17,621	18,668	19,728	20,800	21,884	22,980
76											13,286	14,330	15,386	16,456	17,538	18,633	19,741	20,861	21,994	23,139	24,298
78											14,029	15,131	16,246	17,375	18,518	19,673	20,843	22,025	23,221	24,430	25,653
80											14,792	15,954	17,130	18,320	19,524	20,742	21,974	23,221	24,481	25,756	27,044

[1/] Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.

NOTE.--Block indicates extent of data.

Table 6.—Board-foot volume of ponderosa and Jeffrey pine by Scribner rule in 16-foot logs to a utilized top

Stump and top excluded

Top diameter, variable
Stump height, 1 foot

Diameter breast height outside bark--inches[1]	Total height--Feet																				
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
12	[2]23	27	33	40	51	62	73	84	95	106	117	129	140								
14	30	45	63	81	99	116	134	152	170	188	206	224	242								
16	53	79	106	132	158	184	210	236	262	288	314	340	367								
18	85	121	157	192	228	264	300	335	371	407	442	478	514								
20	123	170	216	263	310	357	403	450	497	544	590	637	684	730	777	824					
22	166	225	285	344	403	462	521	580	639	699	758	817	876	935	944	1,053					
24	215	288	361	434	507	580	653	726	799	872	945	1,018	1,091	1,164	1,237	1,310					
26	270	358	446	534	623	711	799	887	976	1,064	1,152	1,240	1,328	1,417	1,505	1,593					
28		435	540	645	749	854	959	1,064	1,169	1,274	1,379	1,484	1,588	1,693	1,798	1,903					
30		519	642	765	888	1,010	1,133	1,256	1,379	1,502	1,625	1,748	1,871	1,994	2,117	2,240	2,363	2,486	2,608	2,731	2,854
32		610	752	895	1,037	1,179	1,322	1,464	1,606	1,749	1,891	2,034	2,176	2,318	2,461	2,603	2,746	2,888	3,030	3,173	3,315
34			871	1,034	1,198	1,361	1,524	1,687	1,851	2,014	2,177	2,340	2,504	2,667	2,830	2,993	3,157	3,320	3,483	3,647	3,810
36			998	1,184	1,369	1,555	1,741	1,926	2,112	2,297	2,483	2,668	2,854	3,039	3,225	3,411	3,596	3,782	3,967	4,153	4,338
38				1,343	1,553	1,762	1,971	2,180	2,390	2,599	2,808	3,017	3,227	3,436	3,645	3,854	4,064	4,273	4,482	4,691	4,901
40				1,513	1,747	1,981	2,216	2,450	2,684	2,919	3,153	3,388	3,622	3,856	4,091	4,325	4,559	4,794	5,028	5,262	5,497
42				1,692	1,953	2,214	2,475	2,735	2,996	3,257	3,518	3,779	4,040	4,301	4,561	4,822	5,083	5,344	5,605	5,866	6,127
44				1,881	2,170	2,459	2,747	3,036	3,325	3,614	3,902	4,191	4,480	4,769	5,058	5,346	5,635	5,924	6,213	6,502	6,790
46				2,080	2,398	2,716	3,034	3,352	3,671	3,989	4,307	4,625	4,943	5,261	5,579	5,897	6,215	6,534	6,852	7,170	7,488
48				2,289	2,638	2,986	3,335	3,684	4,033	4,382	4,731	5,080	5,428	5,777	6,126	6,475	6,824	7,173	7,522	7,870	8,219
50				2,507	2,888	3,269	3,650	4,031	4,412	4,793	5,174	5,555	5,936	6,317	6,698	7,079	7,460	7,841	8,222	8,603	8,984
52						3,565	3,980	4,394	4,809	5,223	5,638	6,052	6,467	6,882	7,296	7,711	8,125	8,540	8,954	9,369	9,784
54						3,873	4,323	4,772	5,222	5,671	6,121	6,571	7,020	7,470	7,919	8,369	8,818	9,268	9,717	10,167	10,616
56						4,194	4,680	5,166	5,652	6,138	6,624	7,110	7,596	8,082	8,568	9,053	9,539	10,025	10,511	10,997	11,483
58						4,528	5,052	5,575	6,099	6,623	7,147	7,670	8,194	8,718	9,241	9,765	10,289	10,812	11,336	11,860	12,383
60						4,874	5,437	6,000	6,563	7,126	7,689	8,252	8,815	9,378	9,940	10,503	11,066	11,629	12,192	12,755	13,318
62									7,044	7,647	8,251	8,854	9,458	10,061	10,665	11,268	11,872	12,475	13,079	13,682	14,286
64									7,542	8,187	8,833	9,478	10,124	10,769	11,415	12,060	12,706	13,351	13,997	14,642	15,288
66									8,056	8,745	9,434	10,123	10,812	11,501	12,190	12,879	13,568	14,257	14,946	15,635	16,324
68									8,588	9,322	10,055	10,789	11,523	12,257	12,991	13,724	14,458	15,192	15,926	16,659	17,393
70									9,136	9,916	10,696	11,476	12,256	13,036	13,816	14,596	15,376	16,156	16,936	17,716	18,496
72											11,357	12,185	13,012	13,840	14,668	15,495	16,323	17,151	17,978	18,806	19,634
74											12,038	12,914	13,791	14,668	15,544	16,421	17,298	18,175	19,051	19,928	20,805
76											12,738	13,665	14,592	15,519	16,446	17,374	18,301	19,228	20,155	21,082	22,010
78											13,458	14,437	15,416	16,395	17,374	18,353	19,332	20,311	21,290	22,269	23,248
80											14,197	15,230	16,262	17,294	18,327	19,359	20,391	21,424	22,456	23,488	24,521

[1] Diameter classes are midpoint, e.g. 12-inch class includes 11.0-12.9.

NOTE: --Block indicates extent of data.

[2] The volume of a tree with a minimum saw log 8 inches d.i.b. and 12 feet long is 23 board feet. Trees lacking this minimum saw log have no Scribner volume.

Table 7.—Cubic-foot volume of sugar pine

Stump and top excluded

Top diameter, 4 inches
Stump height, 1 foot

Diameter breast height outside bark--inches[1/]	Total height--Feet																				
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
6	2	3	4	4	5	5	6	6	7	8	8	9	9								
8	4	5	6	7	8	9	10	12	13	14	15	16	17								
10	7	8	10	12	14	15	17	19	20	22	24	25	27								
12	10	12	15	17	20	22	25	27	30	32	35	37	40								
14	14	17	21	24	28	31	35	38	42	45	48	52	55								
16	18	23	27	32	37	41	46	50	55	60	64	69	73								
18	23	29	35	41	47	53	59	64	70	76	82	88	94								
20	29	36	44	51	58	66	73	80	87	95	102	109	117	124	131	139					
22	36	44	53	62	71	80	89	98	107	115	124	133	142	151	160	169					
24	43	53	64	74	85	96	106	117	128	138	149	159	170	181	191	202					
26	50	63	75	88	100	113	125	138	150	163	175	188	200	213	225	238					
28		73	88	102	117	131	146	160	175	190	204	219	233	248	263	277					
30		84	101	118	134	151	168	185	202	218	235	252	269	286	302	319	336	353	370	386	403
32		96	115	134	153	173	192	211	230	249	268	288	307	326	345	364	383	403	422	441	460
34			130	152	174	195	217	239	260	282	304	326	347	369	391	412	434	456	477	499	521
36			146	171	195	219	244	268	293	317	341	366	390	415	439	463	488	512	536	561	585
38				191	218	245	272	299	327	354	381	408	436	463	490	517	545	572	599	626	653
40				212	242	272	302	332	363	393	423	453	484	514	544	574	604	635	665	695	725
42				234	267	300	334	367	401	434	467	501	534	567	601	634	668	701	734	768	801
44				257	294	330	367	404	440	477	514	550	587	624	660	697	734	770	807	844	881
46				281	321	361	402	442	482	522	562	602	642	683	723	763	803	843	883	924	964
48				306	350	394	438	482	525	569	613	657	700	744	788	832	876	919	963	1,007	1,051
50				333	380	428	476	523	571	618	666	713	761	808	856	904	951	999	1,046	1,094	1,141
52						463	515	566	618	669	721	772	824	875	927	978	1,030	1,081	1,133	1,184	1,236
54						500	556	611	667	723	778	834	889	945	1,001	1,056	1,112	1,167	1,223	1,279	1,334
56						539	598	658	718	778	838	898	957	1,017	1,077	1,137	1,197	1,257	1,316	1,376	1,436
58						578	642	707	771	835	899	964	1,028	1,092	1,156	1,221	1,285	1,349	1,413	1,478	1,542
60						619	688	757	826	894	963	1,032	1,101	1,170	1,238	1,307	1,376	1,445	1,514	1,582	1,651
62									882	956	1,029	1,103	1,176	1,250	1,323	1,397	1,470	1,544	1,617	1,691	1,765
64									941	1,019	1,098	1,176	1,254	1,333	1,411	1,490	1,568	1,646	1,725	1,803	1,882
66									1,001	1,085	1,168	1,251	1,335	1,418	1,502	1,585	1,669	1,752	1,835	1,919	2,002
68									1,063	1,152	1,241	1,329	1,418	1,506	1,595	1,684	1,772	1,861	1,950	2,038	2,127
70									1,128	1,221	1,315	1,409	1,503	1,597	1,691	1,785	1,879	1,973	2,067	2,161	2,255
72											1,392	1,492	1,591	1,691	1,790	1,890	1,989	2,089	2,188	2,288	2,387
74											1,472	1,577	1,682	1,787	1,892	1,997	2,102	2,207	2,313	2,418	2,523
76											1,553	1,664	1,775	1,886	1,997	2,108	2,219	2,330	2,440	2,551	2,662
78											1,637	1,754	1,870	1,987	2,104	2,221	2,338	2,455	2,572	2,689	2,806
80											1,722	1,845	1,968	2,091	2,214	2,338	2,461	2,584	2,707	2,830	2,953

1/ Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.

NOTE.--Block indicates extent of data.

Table 8.—Board-foot volume of sugar pine by International 1/4-inch rule

Stump and top excluded

Top diameter, 6.5 inches
Stump height, 1 foot

Diameter breast height outside bark--inches[1/]	Total height--Feet																			
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
10	21	27	34	40	48	55	64	73	83	94	106	119	133								
12	40	51	62	74	86	99	113	127	143	160	178	197	217								
14	64	80	98	115	134	153	174	195	218	241	266	293	321								
16	92	116	140	166	192	219	247	276	306	338	372	407	444								
18	125	158	191	224	259	295	332	370	410	451	494	539	586								
20	163	205	248	291	336	382	429	477	527	579	633	689	747	808	871	936					
22	206	259	312	367	422	479	538	598	660	723	789	857	928	1,001	1,077	1,156					
24	254	318	384	451	519	588	659	732	806	883	962	1,044	1,128	1,215	1,305	1,398					
26	306	384	463	543	625	707	792	879	967	1,058	1,152	1,248	1,347	1,449	1,555	1,663					
28		456	549	644	740	838	937	1,039	1,143	1,249	1,358	1,470	1,586	1,704	1,826	1,951					
30		533	643	753	865	979	1,095	1,213	1,333	1,456	1,582	1,711	1,843	1,979	2,119	2,262	2,410	2,562	2,719	2,881	3,048
32		617	743	871	1,000	1,131	1,264	1,399	1,537	1,678	1,822	1,969	2,120	2,275	2,433	2,596	2,763	2,935	3,112	3,294	3,482
34			851	997	1,144	1,293	1,445	1,599	1,756	1,916	2,079	2,246	2,416	2,591	2,770	2,953	3,141	3,334	3,532	3,736	3,945
36			966	1,131	1,298	1,467	1,638	1,813	1,990	2,170	2,353	2,541	2,732	2,927	3,127	3,332	3,542	3,757	3,978	4,205	4,437
38				1,274	1,462	1,652	1,844	2,039	2,237	2,439	2,644	2,853	3,067	3,284	3,507	3,735	3,968	4,206	4,451	4,701	4,958
40				1,425	1,635	1,847	2,061	2,279	2,499	2,724	2,952	3,184	3,421	3,662	3,908	4,160	4,417	4,680	4,950	5,225	5,508
42				1,585	1,818	2,053	2,291	2,532	2,776	3,024	3,276	3,533	3,794	4,060	4,331	4,608	4,891	5,180	5,475	5,777	6,087
44				1,753	2,010	2,270	2,532	2,798	3,067	3,340	3,618	3,900	4,186	4,478	4,776	5,079	5,389	5,705	6,027	6,357	6,694
46				1,930	2,212	2,498	2,786	3,077	3,373	3,672	3,976	4,285	4,598	4,917	5,242	5,573	5,910	6,255	6,606	6,965	7,331
48				2,115	2,424	2,736	3,051	3,370	3,693	4,020	4,351	4,688	5,029	5,377	5,730	6,090	6,456	6,830	7,211	7,600	7,996
50				2,308	2,646	2,986	3,329	3,676	4,027	4,383	4,743	5,109	5,480	5,857	6,240	6,629	7,026	7,430	7,842	8,262	8,691
52						3,246	3,619	3,995	4,376	4,762	5,152	5,548	5,949	6,357	6,771	7,192	7,620	8,056	8,500	8,953	9,414
54						3,517	3,920	4,328	4,739	5,156	5,578	6,005	6,438	6,878	7,324	7,777	8,238	8,707	9,185	9,671	10,166
56						3,799	4,234	4,673	5,117	5,566	6,020	6,480	6,946	7,419	7,899	8,386	8,881	9,384	9,896	10,417	10,947
58						4,092	4,560	5,032	5,509	5,992	6,479	6,973	7,473	7,890	8,495	9,017	9,547	10,086	10,633	11,190	11,757
60						4,395	4,898	5,404	5,916	6,433	6,956	7,485	8,020	8,563	9,113	9,671	10,237	10,812	11,397	11,991	12,596
62									6,337	6,890	7,449	8,014	8,586	9,165	9,752	10,348	10,952	11,565	12,187	12,820	13,463
64									6,773	7,363	7,959	8,561	9,171	9,788	10,414	11,047	11,690	12,342	13,004	13,677	14,360
66									7,223	7,851	8,485	9,127	9,775	10,432	11,097	11,770	12,453	13,145	13,848	14,561	15,285
68									7,687	8,355	9,029	9,710	10,399	11,096	11,801	12,516	13,239	13,973	14,718	15,473	16,240
70									8,166	8,874	9,590	10,312	11,042	11,780	12,527	13,284	14,050	14,827	15,614	16,413	17,223
72											10,167	10,932	11,704	12,485	13,275	14,075	14,885	15,705	16,537	17,380	18,235
74											10,761	11,569	12,386	13,211	14,045	14,889	15,744	16,609	17,486	18,375	19,276
76											11,372	12,225	13,086	13,957	14,836	15,726	16,627	17,538	18,462	19,397	20,346
78											12,000	12,899	13,806	14,723	15,649	16,586	17,534	18,493	19,464	20,448	21,445
80											12,645	13,591	14,546	15,510	16,484	17,469	18,465	19,473	20,493	21,526	22,573

[1/] Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.
NOTE.--Block indicates extent of data.

Table 9.—Board-foot volume of sugar pine by Scribner rule in 16-foot logs to a utilized top

Stump and top excluded

Diameter breast height outside bark-inches[1]	Total height--Feet																				
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
12	25	31	37	43	49	55	61	67	74	80	86	92	98								
14	46	58	69	81	92	104	116	127	139	150	162	173	185								
16	73	91	109	128	146	164	182	201	219	237	255	274	292								
18	105	131	157	183	210	236	262	288	314	341	367	393	419								
20	142	177	212	248	283	319	354	389	425	460	496	531	566	602	637	673					
22	183	229	275	321	367	413	459	505	550	596	642	688	734	780	826	872					
24	230	288	346	403	461	518	576	634	691	749	806	864	922	979	1,037	1,094					
26	282	353	424	494	565	635	706	777	847	918	988	1,059	1,129	1,200	1,271	1,341					
28		424	509	594	679	764	848	933	1,018	1,103	1,188	1,273	1,357	1,442	1,527	1,612					
30		502	602	702	803	903	1,003	1,104	1,204	1,305	1,405	1,505	1,606	1,706	1,806	1,907	2,007	2,107	2,208	2,308	2,408
32		586	703	820	937	1,054	1,171	1,288	1,405	1,522	1,640	1,757	1,874	1,991	2,108	2,225	2,342	2,459	2,577	2,694	2,811
34			811	946	1,081	1,216	1,351	1,487	1,622	1,757	1,892	2,027	2,162	2,297	2,433	2,568	2,703	2,838	2,973	3,108	3,243
36			927	1,081	1,235	1,390	1,544	1,699	1,853	2,008	2,162	2,316	2,471	2,625	2,780	2,934	3,089	3,243	3,397	3,552	3,706
38				1,225	1,400	1,575	1,750	1,925	2,100	2,275	2,450	2,625	2,800	2,975	3,150	3,325	3,500	3,675	3,849	4,024	4,199
40				1,377	1,574	1,771	1,968	2,165	2,361	2,558	2,755	2,952	3,149	3,345	3,542	3,739	3,936	4,132	4,329	4,526	4,723
42				1,539	1,759	1,979	2,198	2,418	2,638	2,858	3,078	3,298	3,518	3,737	3,957	4,177	4,397	4,617	4,837	5,057	5,276
44				1,709	1,953	2,198	2,442	2,686	2,930	3,174	3,418	3,663	3,907	4,151	4,395	4,639	4,883	5,128	5,372	5,616	5,860
46				1,888	2,158	2,428	2,698	2,967	3,237	3,507	3,777	4,046	4,316	4,586	4,856	5,125	5,395	5,665	5,935	6,204	6,474
48				2,076	2,373	2,669	2,966	3,263	3,559	3,856	4,152	4,449	4,746	5,042	5,339	5,636	5,932	6,229	6,525	6,822	7,119
50				2,273	2,598	2,922	3,247	3,572	3,897	4,221	4,546	4,871	5,195	5,520	5,845	6,170	6,494	6,819	7,144	7,468	7,793
52						3,187	3,541	3,895	4,249	4,603	4,957	5,311	5,665	6,019	6,373	6,727	7,082	7,436	7,790	8,144	8,498
54						3,462	3,847	4,232	4,616	5,001	5,386	5,770	6,155	6,540	6,925	7,309	7,694	8,079	8,463	8,848	9,233
56						3,749	4,166	4,582	4,999	5,416	5,832	6,249	6,665	7,082	7,499	7,915	8,332	8,748	9,165	9,581	9,998
58						4,048	4,497	4,947	5,397	5,846	6,296	6,746	7,196	7,645	8,095	8,545	8,995	9,444	9,894	10,344	10,793
60						4,357	4,841	5,325	5,810	6,294	6,778	7,262	7,746	8,230	8,714	9,199	9,683	10,167	10,651	11,135	11,619
62									6,238	6,757	7,277	7,797	8,317	8,837	9,356	9,876	10,396	10,916	11,435	11,955	12,475
64									6,681	7,237	7,794	8,351	8,907	9,464	10,021	10,578	11,134	11,691	12,248	12,805	13,361
66									7,139	7,734	8,329	8,924	9,518	10,113	10,708	11,303	11,898	12,493	13,088	13,683	14,278
68									7,612	8,246	8,881	9,515	10,149	10,784	11,418	12,053	12,687	13,321	13,956	14,590	15,224
70									8,101	8,776	9,451	10,126	10,801	11,476	12,151	12,826	13,501	14,176	14,851	15,526	16,201
72											10,038	10,755	11,472	12,189	12,906	13,623	14,340	15,057	15,774	16,491	17,208
74											10,643	11,403	12,164	12,924	13,684	14,444	15,205	15,965	16,725	17,485	18,246
76											11,266	12,071	12,875	13,680	14,485	15,290	16,094	16,899	17,704	18,508	19,313
78											11,906	12,757	13,607	14,458	15,308	16,159	17,009	17,859	18,710	19,560	20,411
80											12,564	13,462	14,359	15,257	16,154	17,052	17,949	18,847	19,744	20,641	21,539

[1] Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.

NOTE.--Block indicates extent of data.

Table 10.—Cubic-foot volume of lodgepole pine

Stump and top excluded

Top diameter, 4 inches

Diameter breast height outside bark--inches[1/]	Total height--Feet												
	40	50	60	70	80	90	100	110	120	130	140	150	160
6	3	4	5	5	6	6	6						
8	6	7	8	9	10	11	12						
10	9	11	13	15	17	18	20	21	22	23	23	25	26
12	13	16	19	22	25	27	29	31	33	34	35	36	38
14	17	21	26	30	34	37	41	44	46	48	50	52	53
16	22	28	34	39	44	49	54	58	62	65	68	71	73
18	28	35	42	49	57	63	69	74	79	84	88	92	95
20	35	44	52	61	70	78	86	93	99	105	111	116	120
22	42	53	63	74	84	95	104	113	121	129	136	142	148
24	50	63	75	88	101	113	125	135	146	155	164	172	180
26	59	74	88	103	118	133	147	160	172	184	194	204	214
28		86	103	120	137	154	171	186	201	214	227	240	251
30		98	118	137	157	177	196	215	232	248	263	277	291
32		112	134	156	179	201	223	245	265	283	301	318	334
34			151	177	202	227	252	277	300	322	342	361	380
36			170	198	226	254	283	311	338	362	386	408	429
38				221	252	284	315	347	378	405	431	457	481
40				244	279	314	349	384	419	450	480	508	536
42				269	308	346	385	423	462	498	531	563	593
44				296	338	380	422	465	507	548	585	620	654
46				323	369	415	462	508	554	600	641	680	718
48				352	402	452	503	553	603	653	700	743	784
50				382	436	491	545	600	654	709	761	808	854

[1/] Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.

NOTE.--Block indicates extent of data.

Table 11.—Board-foot volume of lodgepole pine by International 1/4-inch rule

Stump and top excluded

Top diameter, 6.5 inches
Stump height, 1 foot

Diameter breast height outside bark--inches[1/]	Total height--Feet												
	40	50	60	70	80	90	100	110	120	130	140	150	160
10	23	39	55	70	86	101	117						
12	43	66	88	110	133	155	178	200	223	245	268	290	313
14	68	98	129	159	190	221	251	282	312	343	374	404	435
16	97	137	177	217	257	297	337	377	417	457	497	537	577
18	132	183	233	284	334	385	436	486	537	587	638	688	739
20	172	234	297	359	421	484	546	609	671	734	796	859	921
22	216	292	367	443	519	594	670	745	821	896	972	1,048	1,123
24	266	356	446	536	626	716	805	895	985	1,075	1,165	1,255	1,345
26	321	426	532	637	743	848	954	1,059	1,165	1,270	1,376	1,482	1,587
28		503	625	747	870	992	1,115	1,237	1,359	1,482	1,604	1,727	1,849
30		585	726	866	1,007	1,147	1,288	1,428	1,569	1,709	1,850	1,990	2,131
32		674	834	994	1,154	1,314	1,474	1,634	1,793	1,953	2,113	2,273	2,433
34			950	1,131	1,311	1,491	1,672	1,852	2,033	2,213	2,394	2,574	2,755
36			1,073	1,276	1,478	1,680	1,883	2,085	2,287	2,490	2,692	2,894	3,097
38				1,430	1,655	1,881	2,106	2,331	2,557	2,782	3,008	3,233	3,459
40				1,592	1,842	2,092	2,342	2,592	2,841	3,091	3,341	3,591	3,841
42				1,764	2,039	2,315	2,590	2,865	3,141	3,416	3,692	3,967	4,242
44				1,944	2,246	2,548	2,851	3,153	3,455	3,757	4,060	4,362	4,664
46				2,133	2,463	2,794	3,124	3,454	3,785	4,115	4,445	4,776	5,106
48				2,330	2,690	3,050	3,410	3,769	4,129	4,489	4,848	5,208	5,568
50				2,537	2,927	3,317	3,708	4,098	4,488	4,879	5,269	5,659	6,050

[1/] Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.
NOTE.--Block indicates extent of data.

Table 12.—Board-foot volume of lodgepole pine by Scribner rule in 16-foot logs to a utilized top

Stump and top excluded | Top diameter, variable Stump height, 1 foot

Diameter breast height outside bark--inches[1/]	Total height--Feet												
	40	50	60	70	80	90	100	110	120	130	140	150	160
12	27	48	68	89	110	130	151	172	192	213	234	254	275
14	48	76	104	132	160	188	216	244	272	301	329	357	385
16	73	109	146	183	220	256	293	330	367	403	440	477	513
18	102	149	195	242	288	335	381	428	474	521	567	614	660
20	137	194	252	309	366	424	481	538	596	653	711	768	825
22	176	245	315	384	453	523	592	662	731	801	870	940	1,009
24	219	302	384	467	550	632	715	798	880	963	1,046	1,128	1,211
26	267	364	461	558	655	752	849	946	1,043	1,140	1,237	1,334	1,431
28		432	545	657	770	882	995	1,107	1,220	1,332	1,445	1,557	1,670
30		506	636	765	894	1,023	1,152	1,281	1,410	1,539	1,669	1,798	1,927
32		586	733	880	1,027	1,174	1,321	1,468	1,615	1,761	1,908	2,055	2,202
34			837	1,003	1,169	1,335	1,501	1,667	1,832	1,998	2,164	2,330	2,496
36			949	1,135	1,320	1,506	1,692	1,878	2,064	2,250	2,436	2,622	2,808
38				1,274	1,481	1,688	1,895	2,103	2,310	2,517	2,724	2,931	3,138
40				1,421	1,651	1,880	2,110	2,340	2,569	2,799	3,028	3,258	3,487
42				1,577	1,830	2,083	2,336	2,589	2,842	3,095	3,348	3,601	3,854
44				1,740	2,018	2,296	2,573	2,851	3,129	3,407	3,684	3,962	4,240
46				1,912	2,215	2,519	2,822	3,126	3,430	3,733	4,037	4,340	4,644
48				2,091	2,422	2,752	3,083	3,413	3,744	4,075	4,405	4,736	5,066
50				2,279	2,637	2,996	3,355	3,713	4,072	4,431	4,789	5,148	5,507

[1/] Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.
NOTE.--Block indicates extent of data.

Table 13.—Cubic-foot volume of white fir

Diameter breast height outside bark[1]	Total height--Feet																				
Inches	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
6	3	3	4	5	5	6	7	7	8	9	9	10	10								
8	5	6	7	8	10	11	12	13	14	15	16	17	19								
10	8	9	11	13	15	17	18	20	22	24	26	27	29								
12	11	14	16	19	21	24	27	29	32	34	37	39	42								
14	15	18	22	26	29	33	36	40	43	47	50	54	57								
16	19	24	29	33	38	43	47	52	56	61	65	70	74								
18	24	30	36	42	48	54	60	66	71	77	83	89	94								
20	30	38	45	52	60	67	74	81	88	95	102	109	116	123	130	137					
22	36	45	54	63	72	81	90	98	107	115	124	132	141	149	157	165					
24	43	54	65	75	86	96	107	117	127	137	147	157	167	177	187	197					
26	51	63	76	88	101	113	125	137	149	161	173	185	196	208	220	231					
28		74	88	102	117	131	145	159	173	187	200	214	228	241	255	269					
30		84	101	118	134	150	166	183	198	214	230	246	261	277	292	308	323	338	353	368	383
32		96	115	134	152	171	189	208	226	244	262	280	297	315	333	350	367	384	401	418	435
34			130	151	172	193	214	234	255	275	296	316	336	356	375	395	415	434	453	472	491
36			146	169	193	216	241	263	286	309	331	354	376	399	421	443	465	486	508	529	551
38				188	215	241	267	293	318	344	369	394	419	444	469	493	518	542	566	590	614
40				209	238	267	296	324	353	381	409	437	465	492	520	547	574	601	627	654	680
42				230	263	294	327	358	389	420	451	482	512	543	573	603	633	662	691	721	750
44				253	288	323	358	393	427	461	495	529	562	596	629	662	694	727	759	791	823
46				276	315	353	391	429	467	504	541	578	615	651	687	723	759	794	829	864	899
48				301	343	385	426	467	508	549	589	629	669	709	748	787	826	864	903	941	979
50				327	372	417	462	507	551	596	639	683	726	769	812	854	896	938	980	1,021	1,062
52						451	500	548	596	644	692	739	785	832	878	924	970	1,015	1,060	1,105	1,149
54						487	539	591	643	695	746	797	847	897	947	996	1,046	1,094	1,143	1,191	1,239
56						524	580	636	692	747	802	857	911	965	1,018	1,072	1,125	1,177	1,229	1,281	1,332
58						562	622	682	742	801	860	919	977	1,035	1,092	1,150	1,206	1,263	1,319	1,374	1,429
60						601	666	730	794	858	921	983	1,046	1,108	1,169	1,230	1,291	1,351	1,411	1,471	1,530
62									848	916	983	1,050	1,117	1,183	1,248	1,314	1,378	1,443	1,507	1,570	1,633
64									903	976	1,048	1,119	1,190	1,260	1,330	1,400	1,469	1,537	1,605	1,673	1,740
66									961	1,038	1,114	1,190	1,265	1,340	1,415	1,489	1,562	1,635	1,707	1,779	1,851
68									1,020	1,101	1,183	1,263	1,343	1,423	1,502	1,580	1,658	1,736	1,812	1,889	1,965
70									1,081	1,167	1,253	1,338	1,423	1,508	1,591	1,674	1,757	1,839	1,921	2,002	2,082
72											1,326	1,416	1,506	1,595	1,684	1,771	1,859	1,946	2,032	2,118	2,203
74											1,400	1,496	1,591	1,685	1,778	1,871	1,964	2,055	2,146	2,237	2,327
76											1,477	1,578	1,678	1,777	1,876	1,974	2,071	2,168	2,264	2,359	2,454
78											1,556	1,662	1,767	1,872	1,976	2,079	2,182	2,283	2,385	2,485	2,585
80											1,637	1,748	1,859	1,969	2,078	2,187	2,295	2,402	2,509	2,614	2,719

1/ Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.

NOTE.--Block indicates extent of data.

Table 14.—Board-foot volume of white fir by International 1/4-inch rule

Stump and top excluded

Top diameter, 6.5 inches
Stump height, 1 foot

Diameter breast height outside bark--inches[1]	Total height--Feet																				
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
10	33	38	42	45	50	57	68	84	107	137	177	226	288								
12	56	66	75	83	92	103	119	140	169	207	255	316	390								
14	84	102	116	130	144	161	182	210	245	291	349	420	507								
16	118	144	166	186	207	230	258	292	335	389	457	539	639								
18	157	193	224	253	281	311	346	388	439	502	579	673	785								
20	201	249	290	328	365	404	446	496	556	628	716	821	947	1,096	1,271	1,475					
22	251	312	365	413	460	508	559	618	687	769	867	984	1,123	1,287	1,479	1,702					
24	306	382	448	508	566	623	685	753	832	924	1,033	1,162	1,314	1,493	1,702	1,944					
26	367	459	539	612	682	751	823	901	990	1,093	1,214	1,355	1,520	1,714	1,940	2,200					
28		542	639	726	808	889	973	1,063	1,163	1,277	1,408	1,562	1,741	1,950	2,192	2,471					
30		633	747	849	946	1,040	1,135	1,237	1,348	1,474	1,618	1,784	1,977	2,201	2,459	2,756	3,047	3,485	3,924	4,419	4,[illegible]
32		730	863	982	1,094	1,202	1,310	1,424	1,548	1,686	1,842	2,021	2,228	2,466	2,741	3,056	3,417	3,828	4,292	4,814	5,[illegible]
34			987	1,125	1,253	1,375	1,498	1,625	1,761	1,911	2,080	2,273	2,493	2,746	3,037	3,371	3,752	4,184	4,673	[illegible]	5,841
36			1,119	1,276	1,422	1,561	1,698	1,839	1,988	2,151	2,333	2,539	2,773	3,042	3,349	3,700	4,100	4,555	5,068	[illegible]	6,[illegible]
38				1,438	1,602	1,757	1,910	2,066	2,229	2,405	2,601	2,820	3,068	3,352	3,674	4,044	4,463	4,939	5,478	[illegible]	6,759
40				1,609	1,792	1,966	2,135	2,306	2,483	2,674	2,883	3,116	3,378	3,676	4,016	4,402	4,840	5,337	[illegible]	[illegible]	[illegible]
42				1,783	1,993	2,186	2,372	2,559	2,751	2,956	3,179	3,426	3,703	4,016	4,371	4,774	5,231	5,748	6,332	6,987	[illegible]
44				1,979	2,205	2,417	2,622	2,825	3,033	3,253	3,490	3,751	4,043	4,371	4,741	5,161	5,637	6,174	[illegible]	[illegible]	[illegible]
46				2,179	2,427	2,660	2,884	3,104	3,324	3,563	3,815	4,091	4,397	4,740	5,126	5,563	6,057	6,613	[illegible]	[illegible]	[illegible]
48				2,388	2,661	2,915	3,158	3,397	3,638	3,888	4,155	4,446	4,766	5,124	5,524	5,979	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50				2,606	2,904	3,181	3,445	3,702	3,961	4,228	4,510	4,815	5,150	5,523	5,941	6,410	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
52						3,459	3,744	4,021	4,297	4,581	4,879	5,199	5,549	5,937	6,370	6,855	7,401	8,014	[illegible]	[illegible]	[illegible]
54						3,748	4,056	4,353	4,648	4,948	5,262	5,598	[illegible]	6,366	6,814	7,315	7,877	8,505	[illegible]	[illegible]	10,897
56						4,050	4,380	4,698	5,012	5,330	5,660	6,012	6,392	6,809	7,273	7,789	8,368	9,017	[illegible]	10,560	11,469
58						4,362	4,716	5,056	5,389	5,726	6,073	6,440	6,835	7,268	7,746	8,278	8,873	9,539	10,286	11,121	12,053
60						4,686	5,065	5,427	5,781	6,136	6,500	6,883	7,294	7,741	8,234	8,781	9,392	10,075	10,840	11,695	12,649
62									6,186	6,560	6,941	7,341	7,767	8,229	8,737	9,299	9,926	10,625	11,407	12,281	13,256
64									6,605	6,998	7,398	7,813	8,255	8,732	9,255	9,832	10,473	11,189	11,988	12,881	13,876
66									7,038	7,450	7,868	8,301	8,758	9,250	9,787	10,379	11,035	11,766	12,582	13,493	14,508
68									7,484	7,917	8,353	8,803	9,276	9,783	10,334	10,940	11,611	12,357	13,189	14,117	15,151
70									7,944	8,398	8,853	9,319	9,808	10,330	10,896	11,516	12,201	12,962	13,810	14,755	15,807
72											9,367	9,851	10,356	10,893	11,473	12,107	12,806	13,581	14,444	15,405	16,475
74											9,895	10,397	10,918	11,470	12,064	12,712	13,425	14,214	15,091	16,067	17,155
76											10,438	10,958	11,495	12,062	12,670	13,331	14,057	14,860	15,751	16,743	17,846
78											10,996	11,533	12,087	12,669	13,291	13,965	14,705	15,520	16,425	17,431	18,550
80											11,568	12,124	12,694	13,290	13,926	14,614	15,366	16,194	17,112	18,132	19,266

[1] Diameter classes are midpoint, e.g., 12-inch class includes 11.0-12.9

NOTE.--Block indicates extent of data.

Table 15.—Board-foot volume of white fir by Scribner rule in 16-foot logs to a utilized top

Stump and top excluded

Top diameter, variable
Stump height, 1 foot

Diameter breast height outside bark--inches[1/]	Total height--Feet																				
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240
12	50	53	55	58	62	68	79	96	119	151	192	243	307								
14	77	85	92	99	108	119	135	158	187	226	275	336	411								
16	109	124	137	150	164	181	203	232	269	315	373	444	530								
18	147	170	190	209	230	255	284	320	364	419	486	567	664								
20	190	222	250	278	307	339	376	420	473	537	614	705	813	939	1,086	1,255					
22	239	281	319	356	394	435	481	534	596	669	756	857	976	1,115	1,275	1,458					
24	293	346	395	443	491	542	598	661	733	816	913	1,025	1,155	1,306	1,478	1,675					
26	352	418	480	539	599	660	727	800	883	977	1,084	1,208	1,349	1,512	1,696	1,906					
28		497	572	644	716	790	868	953	1,047	1,152	1,271	1,405	1,559	1,732	1,929	2,152					
30		583	672	759	844	931	1,022	1,119	1,224	1,341	1,472	1,618	1,783	1,968	2,177	2,411	2,673	2,966	3,292	3,653	4,051
32		675	781	882	982	1,083	1,187	1,297	1,416	1,545	1,687	1,845	2,022	2,219	2,439	2,685	2,959	3,263	3,600	3,973	4,384
34			897	1,015	1,130	1,246	1,365	1,489	1,621	1,763	1,918	2,088	2,276	2,484	2,716	2,972	3,257	3,572	3,920	4,303	4,725
36			1,021	1,156	1,289	1,421	1,555	1,694	1,840	1,995	2,163	2,345	2,545	2,765	3,007	3,274	3,569	3,894	4,251	4,643	5,074
38				1,307	1,458	1,607	1,757	1,911	2,072	2,242	2,423	2,618	2,829	3,060	3,313	3,590	3,894	4,227	4,593	4,993	5,430
40				1,467	1,637	1,804	1,972	2,142	2,318	2,502	2,697	2,905	3,129	3,371	3,634	3,920	4,233	4,574	4,946	5,352	5,795
42				1,636	1,826	2,012	2,198	2,386	2,578	2,777	2,986	3,207	3,443	3,696	3,969	4,264	4,584	4,932	5,310	5,721	6,167
44				1,814	2,025	2,232	2,437	2,643	2,852	3,067	3,290	3,525	3,772	4,036	4,319	4,622	4,950	5,303	5,686	6,099	6,547
46				2,001	2,235	2,463	2,688	2,913	3,139	3,371	3,609	3,857	4,117	4,391	4,683	4,995	5,328	5,687	6,072	6,488	6,935
48				2,198	2,455	2,705	2,951	3,195	3,440	3,688	3,942	4,204	4,476	4,761	5,062	5,381	5,720	6,082	6,470	6,885	7,331
50				2,403	2,685	2,959	3,227	3,491	3,755	4,021	4,290	4,566	4,851	5,146	5,456	5,782	6,126	6,491	6,879	7,293	7,735
52						3,223	3,514	3,800	4,084	4,367	4,653	4,943	5,240	5,546	5,864	6,196	6,544	6,911	7,299	7,710	8,146
54						3,499	3,814	4,122	4,426	4,728	5,030	5,335	5,645	5,961	6,287	6,625	6,976	7,344	7,730	8,136	8,566
56						3,786	4,126	4,457	4,782	5,103	5,422	5,742	6,064	6,391	6,725	7,068	7,422	7,789	8,172	8,573	8,993
58						4,085	4,450	4,805	5,152	5,492	5,829	6,164	6,499	6,836	7,177	7,525	7,881	8,247	8,625	9,019	9,428
60						4,394	4,786	5,166	5,535	5,896	6,251	6,601	6,948	7,296	7,644	7,996	8,353	8,717	9,090	9,474	9,872
62									5,932	6,314	6,687	7,053	7,413	7,770	8,125	8,481	8,838	9,199	9,566	9,940	10,322
64									6,343	6,746	7,138	7,520	7,893	8,260	8,622	8,980	9,337	9,694	10,052	10,414	10,781
66									6,768	7,193	7,603	8,001	8,388	8,764	9,132	9,493	9,849	10,201	10,550	10,899	11,248
68									7,206	7,654	8,084	8,498	8,897	9,284	9,658	10,021	10,375	10,721	11,060	11,393	11,723
70									7,658	8,129	8,579	9,010	9,422	9,818	10,198	10,562	10,914	11,252	11,580	11,897	12,205
72											9,089	9,536	9,962	10,367	10,752	11,118	11,466	11,797	12,111	12,410	12,695
74											9,613	10,078	10,517	10,931	11,321	11,688	12,032	12,353	12,654	12,933	13,193
76											10,152	10,634	11,087	11,510	11,905	12,272	12,611	12,922	13,207	13,466	13,699
78											10,706	11,206	11,672	12,104	12,504	12,870	13,203	13,504	13,772	14,009	14,213
80											11,274	11,792	12,272	12,713	13,117	13,482	13,809	14,097	14,348	14,561	14,735

1/ Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.
NOTE.--Block indicates extent of data.

Table 16.—Cubic-foot volume of California red fir

Stump and top excluded

Top diameter, 4 inches
Stump height, 1 foot

Diameter breast height outside bark--inches[1/]	Total height--Feet																
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
6	3	4	5	5	6	7	8	9	9	10	11	12	13				
8	5	7	8	10	11	13	14	15	17	18	20	21	22				
10	8	10	13	15	17	20	22	24	26	28	31	33	35				
12	10	14	18	22	25	28	31	35	38	41	44	47	50				
14	13	18	23	28	34	38	43	47	51	56	60	64	68				
16	17	22	28	35	42	49	56	61	67	73	78	84	89				
18	21	27	34	42	50	59	69	78	85	92	99	106	113				
20	26	33	41	50	60	70	81	93	105	113	122	131	140	148	157	166	
22	32	40	49	59	70	82	95	108	122	136	148	158	169	180	190	201	
24	38	47	57	69	82	95	110	125	140	157	174	188	201	214	226	239	
26	44	55	66	79	94	109	125	142	160	178	198	218	236	251	265	280	
28		64	77	90	107	124	142	161	181	201	223	245	268	291	308	325	
30		74	88	103	120	140	160	181	203	225	249	274	300	326	353	373	393
32		84	101	117	135	156	178	202	226	251	277	304	333	362	392	423	447
34			113	132	151	174	198	224	250	278	307	336	367	399	432	466	501
36			127	148	170	192	219	247	276	306	337	370	403	438	473	510	548
38				165	189	213	241	271	303	335	369	405	441	478	517	557	598
40				183	209	236	263	296	331	366	403	441	480	521	562	605	649
42				202	231	260	289	323	360	398	438	479	521	565	610	656	703
44				222	253	285	317	350	390	432	474	518	564	611	659	708	759
46				242	277	312	346	381	422	466	512	559	608	658	709	762	817
48				264	302	339	377	415	455	502	551	602	654	707	762	818	876
50				286	327	368	409	450	491	540	592	646	701	758	816	876	938
52						398	442	487	531	578	634	691	750	811	873	936	1,002
54						429	477	525	573	620	678	738	801	865	931	998	1,067
56						462	513	564	616	667	722	787	853	921	991	1,062	1,135
58						495	550	605	661	716	771	837	907	979	1,052	1,128	1,205
60						530	589	648	707	766	825	889	962	1,038	1,116	1,196	1,277
62									755	818	881	943	1,020	1,100	1,181	1,265	1,351
64									804	871	938	1,005	1,078	1,162	1,249	1,337	1,427
66									855	927	998	1,069	1,140	1,227	1,318	1,410	1,504
68									908	984	1,059	1,135	1,211	1,293	1,388	1,485	1,584
70									962	1,042	1,122	1,203	1,283	1,363	1,461	1,563	1,666
72											1,188	1,272	1,357	1,442	1,535	1,642	1,750
74											1,254	1,344	1,434	1,523	1,613	1,723	1,836
76											1,323	1,418	1,512	1,607	1,701	1,806	1,924
78											1,394	1,493	1,593	1,692	1,792	1,891	2,014
80											1,466	1,571	1,676	1,780	1,885	1,990	2,106

[1/] Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.
NOTE.--Block indicates extent of data.

Table 17.—Board-foot volume of California red fir by International 1/4-inch rule

Top diameter, 6.5 inches
Stump height, 1 foot

Diameter breast height outside bark--	Total height- feet																
	[illegible]	[illegible]	60	70	80	[illegible]	100	110	120	130	140	150	160	170	180	190	200
10	[illegible]	51	66	84	105	[illegible]	[illegible]	189	227	269	315	372	433				
12	[illegible]	72	92	115	142	[illegible]	209	[illegible]	[illegible]	349	409	477	552				
[illegible]	[illegible]	[illegible]	121	150	184	[illegible]	267	[illegible]	[illegible]	438	[illegible]	[illegible]	681				
[illegible]	[illegible]	122	[illegible]	[illegible]	232	[illegible]	[illegible]	[illegible]	460	536	621	716	822				
[illegible]	117	153	192	236	285	341	404	474	554	642	741	851	973				
[illegible]	[illegible]	187	233	286	[illegible]	[illegible]	[illegible]	564	656	758	871	996	1,135	1,288	1,455	1,638	
[illegible]	173	[illegible]	279	340	408	483	568	661	766	881	1,010	1,152	1,308	1,479	1,667	1,872	
[illegible]	205	[illegible]	329	399	477	564	[illegible]	766	884	1,014	1,158	1,317	1,491	1,683	1,892	2,119	
[illegible]	240	308	382	463	[illegible]	650	758	878	1,010	[illegible]	1,316	1,492	1,686	1,897	2,128	2,379	
28	[illegible]	355	[illegible]	532	[illegible]	742	864	997	1,144	1,306	1,483	1,678	1,891	2,123	2,376	2,652	
[illegible]	[illegible]	[illegible]	502	605	718	841	976	1,124	1,286	1,465	1,660	1,873	2,107	2,361	2,637	2,937	3,262
[illegible]	[illegible]	[illegible]	567	683	809	946	1,095	1,258	[illegible]	1,632	1,846	2,079	2,333	2,610	2,910	3,235	3,587
[illegible]	[illegible]	[illegible]	[illegible]	766	905	1,056	1,220	1,400	1,595	1,809	2,041	2,295	2,571	2,870	3,195	3,546	3,926
36	[illegible]	[illegible]	[illegible]	853	1,007	1,173	1,353	1,549	1,762	[illegible]	2,246	2,521	2,819	3,142	3,492	3,870	4,278
38	[illegible]	[illegible]	[illegible]	[illegible]	1,114	1,296	[illegible]	1,705	1,936	2,188	2,461	2,757	3,078	3,425	3,801	4,207	4,644
40	[illegible]	[illegible]	[illegible]	1,043	1,226	1,424	1,638	1,869	2,119	[illegible]	2,684	3,003	3,347	3,720	4,122	4,556	5,023
[illegible]	[illegible]	[illegible]	[illegible]	1,144	[illegible]	1,559	[illegible]	2,040	2,310	2,602	2,918	3,259	3,628	4,026	4,456	4,918	5,415
44	[illegible]	[illegible]	[illegible]	1,251	1,468	1,700	1,950	2,219	2,509	2,822	3,160	3,525	3,919	4,344	4,801	5,293	5,821
[illegible]	[illegible]	[illegible]	[illegible]	1,362	1,596	1,847	2,116	2,405	2,716	3,051	3,412	3,802	4,221	4,673	5,159	5,681	6,241
[illegible]	[illegible]	[illegible]	[illegible]	1,477	[illegible]	2,000	2,289	[illegible]	[illegible]	3,289	3,674	4,088	[illegible]	5,013	5,528	6,081	6,674
50	[illegible]	[illegible]	[illegible]	1,598	1,870	[illegible]	2,468	2,799	[illegible]	3,535	[illegible]	4,385	4,858	5,365	5,910	6,494	7,120
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2,324	[illegible]	3,007	3,385	[illegible]	4,225	4,691	5,192	5,729	6,304	6,921	7,580
54	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2,495	2,847	3,223	3,624	4,054	[illegible]	5,008	5,537	6,104	6,710	7,359	8,053
56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2,673	3,047	3,446	3,872	[illegible]	4,814	5,335	5,893	6,490	7,129	7,811	8,540
58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2,856	[illegible]	3,677	4,127	4,608	5,123	[illegible]	6,260	6,888	7,559	8,276	9,041
60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3,045	3,467	3,914	[illegible]	[illegible]	5,441	6,019	6,637	[illegible]	8,001	8,753	9,554
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4,662	5,198	5,768	6,376	7,025	7,718	8,456	9,243	10,081
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4,942	5,505	6,105	6,744	7,424	8,150	8,923	9,746	10,622
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5,230	5,822	6,451	7,121	7,834	8,593	9,401	10,261	11,176
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5,526	6,147	6,807	[illegible]	8,255	9,048	9,892	10,790	11,744
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5,830	6,481	[illegible]	7,906	8,686	9,515	10,395	11,331	12,325
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7,547	8,314	9,128	9,993	10,911	11,885	12,920
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8,732	9,581	10,482	11,438	12,452	13,528
76	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8,324	9,160	10,045	10,983	11,977	13,032	14,149
78	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8,727	9,598	10,519	11,495	12,529	13,624	14,784
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10,046	11,004	12,019	13,093	14,229	15,432

1/ Diameter classes are midpoint; e.g., [illegible] includes 11.0-12.9.
NOTE.--Block indicates extent of data.

Table 18.—Board-foot volume of California red fir by Scribner rule in 16-foot logs to a utilized top

Stump and top excluded

Top diameter, variable
Stump height, 1 foot

Diameter breast height outside bark--inches 1/	Total height--Feet																
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
12	24	41	60	81	105	133	164	199	239	284	334	390	452				
14	38	60	84	112	142	177	215	259	308	363	424	491	566				
16	54	82	113	147	185	227	274	327	385	451	523	603	692				
18	74	108	146	187	233	284	340	402	471	548	633	726	828				
20	96	138	183	232	287	346	412	485	565	654	752	859	976	1,105	1,245	1,398	
22	121	171	224	283	346	416	492	576	668	769	880	1,002	1,135	1,280	1,438	1,610	
24	149	207	270	337	411	491	578	674	779	894	1,019	1,156	1,305	1,468	1,644	1,836	
26	179	247	320	397	481	573	672	780	898	1,027	1,167	1,320	1,487	1,667	1,863	2,075	
28		290	373	462	557	661	772	894	1,026	1,169	1,325	1,495	1,679	1,878	2,094	2,327	
30		337	431	532	639	755	880	1,015	1,162	1,321	1,493	1,680	1,882	2,101	2,338	2,593	2,867
32		388	494	606	726	855	994	1,144	1,306	1,481	1,671	1,876	2,097	2,336	2,594	2,871	3,170
34			560	685	819	962	1,115	1,281	1,459	1,651	1,858	2,082	2,323	2,583	2,863	3,163	3,487
36			631	770	917	1,075	1,244	1,425	1,620	1,829	2,055	2,298	2,560	2,841	3,144	3,469	3,817
38				859	1,021	1,194	1,379	1,577	1,789	2,017	2,262	2,525	2,808	3,112	3,438	3,787	4,161
40				953	1,131	1,320	1,521	1,737	1,967	2,214	2,479	2,763	3,067	3,394	3,744	4,119	4,520
42				1,051	1,246	1,452	1,671	1,904	2,153	2,420	2,705	3,010	3,338	3,688	4,063	4,464	4,892
44				1,155	1,366	1,590	1,827	2,079	2,348	2,634	2,941	3,269	3,619	3,994	4,394	4,822	5,278
46				1,264	1,493	1,734	1,990	2,261	2,550	2,858	3,187	3,537	3,912	4,312	4,738	5,193	5,678
48				1,377	1,624	1,885	2,160	2,452	2,762	3,091	3,442	3,817	4,216	4,641	5,095	5,578	6,093
50				1,496	1,762	2,042	2,337	2,650	2,981	3,333	3,708	4,106	4,531	4,983	5,464	5,976	6,521
52						2,205	2,521	2,855	3,209	3,584	3,983	4,406	4,857	5,336	5,845	6,387	6,963
54						2,374	2,712	3,069	3,445	3,844	4,268	4,717	5,194	5,701	6,239	6,811	7,418
56						2,550	2,910	3,289	3,690	4,114	4,562	5,038	5,543	6,078	6,646	7,249	7,888
58						2,732	3,115	3,518	3,943	4,392	4,867	5,369	5,902	6,467	7,065	7,700	8,372
60						2,920	3,327	3,754	4,204	4,679	5,181	5,711	6,273	6,867	7,497	8,164	8,870
62									4,474	4,976	5,505	6,064	6,655	7,280	7,941	8,641	9,381
64									4,752	5,281	5,838	6,427	7,048	7,704	8,398	9,132	9,907
66									5,039	5,595	6,182	6,800	7,452	8,140	8,867	9,635	10,446
68									5,333	5,919	6,535	7,184	7,867	8,588	9,349	10,152	11,000
70									5,637	6,252	6,898	7,578	8,294	9,048	9,844	10,683	11,567
72											7,270	7,982	8,731	9,520	10,351	11,226	12,149
74											7,653	8,397	9,180	10,004	10,870	11,783	12,744
76											8,045	8,823	9,640	10,499	11,402	12,353	13,353
78											8,447	9,259	10,111	11,006	11,947	12,936	13,976
80											8,859	9,705	10,593	11,525	12,504	13,532	14,613

1/ Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.
NOTE.--Block indicates extent of data.

Table 19.—Cubic-foot volume of incense-cedar

Top diameter, 4 inches
Stump height, 1 foot

Diameter breast height outside bark-- 1/	Total height--Feet														
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
6	5	3	4	4	4	5	5	6	6	7	7	8	8		
8	5	5	6	7	8	9	9	10	11	12	13	14	15		
10	7	9	10	11	12	14	15	16	18	19	21	22	24		
12	11	12	14	16	18	19	21	23	25	28	30	32	34		
14	14	17	19	22	24	26	29	32	35	38	40	43	46		
16	19	22	25	28	31	35	38	41	45	49	53	57	60		
18	24	28	32	36	40	44	48	52	57	62	67	72	76		
20	29	34	39	44	49	54	59	65	71	77	82	88	94	100	106
22	36	42	47	53	59	65	71	78	86	93	100	107	114	121	128
24	42	49	57	64	71	78	85	93	102	110	119	127	136	144	153
26	50	58	66	75	83	91	100	110	119	129	139	149	159	169	179
28		67	77	87	96	106	116	127	139	150	162	173	185	196	208
30		77	88	99	110	122	133	146	159	172	186	199	212	225	239
32		88	100	113	126	138	151	166	181	196	211	226	241	256	271
34			113	128	142	156	170	187	204	221	238	255	272	289	306
36			127	143	159	175	191	210	229	248	267	286	305	324	344
38				159	177	195	213	234	255	276	298	319	340	361	383
40				177	196	216	236	259	283	306	330	353	377	401	424
42				195	217	238	260	286	312	338	364	390	416	442	468
44				214	238	261	285	314	342	371	399	428	456	485	513
46				234	260	286	312	343	374	405	436	467	499	530	561
48				254	283	311	340	373	407	441	475	509	543	577	611
50				276	307	338	368	405	442	479	515	552	589	626	663
52						365	399	438	478	518	557	597	637	677	717
54						394	430	472	515	558	601	644	687	730	773
56						424	462	508	554	600	647	693	739	785	831
58						454	496	545	594	644	694	743	793	842	892
60						486	531	583	636	689	742	795	848	901	954
62						519	567	623	679	736	793	849	906	962	1,019
64						553	604	664	724	784	844	905	965	1,025	1,086
66						588	642	706	770	834	898	962	1,026	1,091	1,155
68									817	885	953	1,021	1,090	1,158	1,226
70									866	938	1,010	1,082	1,155	1,227	1,299
72											1,069	1,145	1,221	1,298	1,374
74											1,129	1,210	1,290	1,371	1,452
76											1,191	1,276	1,361	1,446	1,531
78											1,254	1,344	1,434	1,523	1,613
80											1,319	1,414	1,508	1,602	1,696

1/ Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.
NOTE.--Block indicates extent of data.

Table 20.—Board-foot volume of incense-cedar by International 1/4-inch rule

Stump and top excluded

Top diameter, 6.5 inches
Stump height, 1 foot

Diameter breast height outside bark--inches[1/]	Total height--Feet														
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
10	31	40	49	58	68	79	90	102	116	130	145	162	180		
12	45	57	70	84	98	113	130	147	166	187	209	233	259		
14	61	78	95	114	133	154	177	201	227	255	285	317	352		
16	80	102	125	149	174	201	231	262	296	332	372	414	460		
18	101	129	158	188	220	255	292	332	375	421	470	524	582		
20	125	159	195	232	272	315	360	410	462	519	581	647	718	795	877
22	151	192	235	281	329	381	436	496	560	629	703	783	869	962	1,061
24	180	229	280	334	392	453	519	590	666	748	836	932	1,034	1,144	1,263
26	212	269	329	392	460	532	609	692	782	878	982	1,093	1,214	1,343	1,483
28		312	381	455	533	617	707	803	906	1,018	1,138	1,268	1,408	1,558	1,719
30		358	438	522	612	708	811	922	1,041	1,169	1,307	1,456	1,616	1,788	1,974
32		407	498	594	696	806	923	1,049	1,184	1,330	1,487	1,656	1,838	2,035	2,246
34			562	671	786	910	1,042	1,184	1,337	1,501	1,678	1,870	2,075	2,297	2,535
36			630	752	882	1,020	1,168	1,327	1,498	1,683	1,882	2,096	2,327	2,575	2,842
38				838	982	1,136	1,301	1,479	1,670	1,875	2,097	2,335	2,592	2,869	3,167
40				928	1,088	1,259	1,442	1,638	1,850	2,078	2,323	2,588	2,873	3,179	3,509
42				1,024	1,200	1,388	1,590	1,806	2,040	2,291	2,561	2,853	3,167	3,505	3,869
44				1,123	1,317	1,523	1,745	1,983	2,238	2,514	2,811	3,131	3,476	3,847	4,246
46				1,228	1,439	1,665	1,907	2,167	2,447	2,748	3,072	3,422	3,799	4,204	4,641
48				1,337	1,567	1,813	2,076	2,359	2,664	2,992	3,345	3,726	4,136	4,578	5,053
50				1,451	1,700	1,967	2,253	2,560	2,890	3,246	3,630	4,043	4,488	4,967	5,483
52						2,128	2,437	2,769	3,126	3,511	3,926	4,373	4,855	5,373	5,930
54						2,294	2,628	2,986	3,371	3,787	4,234	4,716	5,235	5,794	6,395
56						2,468	2,826	3,211	3,626	4,072	4,553	5,072	5,630	6,231	6,877
58						2,647	3,032	3,445	3,889	4,368	4,884	5,441	6,039	6,684	7,377
60						2,833	3,244	3,686	4,162	4,675	5,227	5,822	6,463	7,153	7,895
62						3,025	3,464	3,936	4,444	4,992	5,581	6,217	6,901	7,638	8,430
64						3,223	3,691	4,194	4,736	5,319	5,947	6,624	7,354	8,139	8,983
66						3,428	3,926	4,461	5,036	5,657	6,325	7,045	7,820	8,655	9,553
68									5,346	6,005	6,714	7,478	8,302	9,188	10,141
70									5,665	6,363	7,115	7,925	8,797	9,736	10,746
72											7,527	8,384	9,307	10,300	11,369
74											7,951	8,856	9,831	10,881	12,009
76											8,387	9,341	10,370	11,477	12,667
78											8,834	9,840	10,923	12,089	13,343
80											9,293	10,351	11,490	12,717	14,036

[1/] Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.
NOTE.--Block indicates extent of data.

Table 21.—Board-foot volume of incense-cedar by Scribner rule in 16-foot logs to a utilized top

Top diameter, variable
Stump height, 1 foot

Diameter breast height inches[1]	Total height--Feet														
	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
12	27	33	40	47	53	60	66	73	80	86	93	99	106		
14	42	53	63	74	84	95	105	116	126	137	147	158	168		
16	61	76	91	106	122	137	152	167	182	198	213	228	243		
18	84	103	124	145	165	186	207	227	248	269	289	310	331		
20	108	135	162	189	216	242	269	296	323	350	377	404	431	458	485
22	136	170	204	238	272	306	340	374	408	442	476	510	544	578	612
24	167	209	251	293	335	377	419	460	502	544	586	628	670	712	754
26	202	253	303	354	404	455	505	556	606	657	707	758	808	859	909
28		300	360	420	480	540	600	660	720	780	839	899	959	1,019	1,079
30		351	421	491	561	632	702	772	842	913	983	1,053	1,123	1,193	1,264
32		406	487	569	650	731	812	894	975	1,056	1,137	1,219	1,300	1,381	1,462
34			559	651	745	838	931	1,024	1,117	1,210	1,303	1,396	1,489	1,582	1,675
36			634	740	846	951	1,057	1,163	1,268	1,374	1,480	1,585	1,691	1,797	1,903
38				834	953	1,072	1,191	1,310	1,429	1,548	1,668	1,787	1,906	2,025	2,144
40				933	1,067	1,200	1,333	1,467	1,600	1,733	1,867	2,000	2,133	2,267	2,400
42				1,038	1,187	1,335	1,483	1,632	1,780	1,928	2,077	2,225	2,373	2,522	2,670
44				1,149	1,313	1,477	1,641	1,806	1,970	2,134	2,298	2,462	2,626	2,790	2,955
46				1,265	1,446	1,627	1,807	1,988	2,169	2,350	2,530	2,711	2,892	3,073	3,253
48				1,387	1,585	1,783	1,981	2,179	2,378	2,576	2,774	2,972	3,170	3,368	3,566
50				1,514	1,731	1,947	2,163	2,379	2,596	2,812	3,028	3,245	3,461	3,677	3,894
52						2,118	2,353	2,588	2,824	3,059	3,294	3,529	3,765	4,000	4,235
54						2,296	2,551	2,806	3,061	3,316	3,571	3,826	4,081	4,336	4,591
56						2,481	2,756	3,032	3,308	3,583	3,859	4,135	4,410	4,686	4,962
58						2,673	2,970	3,267	3,564	3,861	4,158	4,455	4,752	5,049	5,346
60						2,872	3,192	3,511	3,830	4,149	4,468	4,787	5,107	5,426	5,745
62						3,079	3,421	3,763	4,105	4,448	4,790	5,132	5,474	5,816	6,158
64						3,293	3,659	4,025	4,390	4,756	5,122	5,488	5,854	6,220	6,586
66						3,514	3,904	4,294	4,685	5,075	5,466	5,856	6,247	6,637	7,027
68									4,989	5,405	5,820	6,236	6,652	7,068	7,483
70									5,303	5,744	6,186	6,628	7,070	7,512	7,954
72											6,563	7,032	7,501	7,970	8,438
74											6,951	7,448	7,944	8,441	8,937
76											7,351	7,876	8,401	8,926	9,451
78											7,761	8,315	8,870	9,424	9,978
80											8,182	8,767	9,351	9,936	10,520

[1] Diameter classes are midpoint; e.g., 12-inch class includes 11.0-12.9.
NOTE.--Block indicates extent of data.

Table 22—Root mean squared errors of form factor equations

Species	Ratio	Int[illegible] 1/4-in		[illegible]ner	
			Percent		
Douglas-fir	[illegible]	11.7	0.31	14.8	17.3
Ponderosa [illegible]	.05	[illegible]	.40	17.6	20.9
Sugar [illegible]	.05	15.5	.44	19.[illegible]	.45 21.7
Lodgepol[illegible]	[illegible]	10.9	.32	[illegible]	.33 16.6
White fir	[illegible]	13.2	[illegible]	17.0	.36 18.9
California red fir	.04	13.5	[illegible]	18.0	.38 20.3
Incense-cedar	.04	14.[illegible]	.31	19.0	.29 21.6

Table 23—Results of a test of study equations and the old local volume tables against 441 trees of known volume from the Stanislaus National Forest

Species and log rule	Mean volume per tree	Root mean squared error 1/		Aggregate difference	
		Study equations	[illegible] volume tables	Study equations	Old local volume tables
			Percent		
Douglas-fir (115 trees):					
Cubic	114.6	19.2	27.7	10.1	-0.5
International 1/4-inch	[illegible]	24.9	51.0	9.1	-8.3
Scribner	677.1	31.1	[illegible]	10.7	-1.2
Ponderosa and Jeffrey pine (146 trees):					
Cubic	158.9	20.2	31.7	4.6	-8.5
International 1/4-inch	1,120.1	26.9	56.7	2.0	-17.0
Scribner	1,009.2	29.5	49.5	3.4	-13.3
Sugar pine (34 trees):					
Cubic	214.5	13.0	20.8	-5.2	-6.7
International 1/4-inch	1,546.5	17.6	32.1	10.3	-13.9
Scribner	1,417.[illegible]	43.0	38.0	-9.9	-10.9
Lodgepole pine (60 trees):					
Cubic	79.0	15.8	50.5	3.8	35.0
International 1/4-inch	457.2	25.4	60.0	7.9	36.2
Scribner	411.6	30.0	77.4	4.7	41.0
White fir (86 trees):					
Cubic	168.3	15.7	22.4	-6.2	-10.8
International 1/4-inch	1,197.6	21.4	31.2	-9.7	-15.0
Scribner	1,096.7	38.1	52.4	-9.8	-12.5
California red fir (42 trees):					
Cubic	284.9	17.2	28.3	-2.6	-.1
International 1/4-inch	2,044.0	24.8	[illegible]	10.2	-5.2
Scribner	1,892.6	28.1	[illegible]	-10.7	-2.5
Incense-cedar (58 trees):					
Cubic	117.3	20.5	[illegible]	-.6	-20.7
International 1/4-inch	769.9	28.1	52.8	-2.5	-23.1
Scribner	679.4	51.7	65.7	-5.0	-17.9
Combined (441 trees):					
Cubic	159.2	17.9	32.9	-.3	-5.4
International 1/4-inch	1,108.1	24.9	47.5	-3.8	-11.6
Scribner	1,005.9	34.8	43.8	-3.9	-8.1

1/ Logarithmic transformation [illegible]

Table 24—Comparative reliability of diameter-height and diameter-height-form class volume equations in estimating Stanislaus National Forest sample tree volumes

(In percent)

Equation	Cubic		International 1/4-inch		Scribner	
	Root mean squared error[1/]	Aggregate difference	Root mean squared error[1/]	Aggregate difference	Root mean squared error[1/]	Aggregate difference
Without form class	16.2	-0.6	20.1	-4.5	23.3	-4.4
With actual form class	12.0	5.4	13.0	1.7	16.3	1.7
With average form class	16.2	-1.8	20.5	-5.7	23.7	-5.5

[1/] In order to equalize variance, root mean squared errors were calculated for four factors instead of volume.

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PNW-267 January 1976

UTILIZATION OF HARDWOOD BROWSE BY MOOSE ON THE TANANA FLOOD PLAIN OF INTERIOR ALASKA

by

Jerry O. Wolff[1/]

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ABSTRACT

The point-center-quarter and Shafer twig-count methods were used to estimate availability of hardwood browse and consumption by moose on the Tanana River flood plain near Fairbanks, Alaska. In 8- and 15-year-old stands, respectively, 38 and 113 kg/ha of available hardwood browse were present. About 55 percent of the available forage was consumed by moose in both areas during the 1974-75 winter. Willows were the most abundant shrubs present and provided the most winter forage for moose.

Keywords: Hardwood browse, Alaska, moose.

[1/] Jerry O. Wolff was a part-time Station employee with the Institute of Northern Forestry at the time this manuscript was prepared. He is now with the Museum of Vertebrate Zoology, University of California, Berkeley.

INTRODUCTION

During the winter, moose (*Alces alces*) in Alaska feed primarily on the shoots and branches of willow (*Salix* spp.), birch (*Betula papyrifera*), aspen (*Populus tremuloides*), and balsam poplar (*Populus balsamifera*) (Seemel 1969; LeResche and Davis 1973; Cushwa and Coady, in press). These hardwood plant species are frequently found in early successional stage plant communities established after fire, logging, or alluvial deposits resulting from flood plain processes (Viereck 1973). Along rivers, active erosion and deposition resulting from spring runoff and occasional flooding create new areas available for the development of early successional stages. Annual production of available forage for browsing mammals is greater during the first 20 years following a disturbance than in later years[2/] (Spencer and Chatelain 1953, Viereck 1973). In general, disturbances which occur every 20 years or less result in maximized forage production for browsing mammals.

The willow-dominated early successional stage plant communities, which may occupy from 1 to over 100 ha, occur frequently along the major river systems of interior Alaska and are used as winter foraging grounds by moose. This study was designed to estimate amount of available browse in two areas along the Tanana River flood plain southwest of Fairbanks, Alaska, and to determine the importance of these two areas as winter foraging habitat for moose. These two areas are representative of early seral plant communities, and the results of this study should be applicable to other similar areas along the river.

[2/] Wolff, J. O. [n.d.] Production of willow browse in a burn and a mature black spruce forest in interior Alaska. Unpublished manuscript. (On file at U.S. Dep. Agric., Pac. Northwest Forest & Range Exp. Stn., Inst. North. For., Fairbanks, Alaska.)

STUDY AREAS

The two study sites were located about 20 km southwest of Fairbanks, Alaska, on recently deposited bars along the Tanana River. The two stands were 8 and 15 years old and supported several species of willow, balsam poplar, alder (*Alnus tenuifolia*), and seedlings of white spruce (*Picea glauca*) (fig. 1).

METHODS

The densities of shrubs and trees in the 8-year-old stand were determined by the point-center-quarter method (Cottam and Curtis 1956) using 40 points. Densities of shrubs and trees in the 15-year-old stand were determined by a modification of the Ohmann-Ream (1971) method. Although the two sampling methods are not known to be comparable, the resultant densities appeared to be reasonable. Pellet group counts were made in forty 250-m^2 circular plots in each area. The Shafer (1965) twig-count method was used to estimate the availability and utilization of hardwood browse. Estimates of available browse included all twigs less than 4 mm in diameter lying above snowline and within browsing reach of moose. Browsing reach was considered to be between 50 cm and 5 m above the ground. Moose can reach to 3 m and can break taller stems if the diameter at breast height is less than 4 cm.

A brief description of the Shafer twig-count method follows: In May 1975, the total numbers of browsed and unbrowsed branches were counted on 40 to 100 shrubs of each species in each area. Only current annual growth was included in the sampling. The diameter at point of browsing was measured on 50 browsed branches of each species. Fifty unbrowsed twigs of the same

Figure 1.--Photo of the 8-year-old stand along the Tanana River near Fairbanks, Alaska.

diameter were clipped, ovendried, and weighed in order to determine a mean weight per twig. The weight per twig was multiplied by the number of branches available per shrub and the number of shrubs per hectare to provide an estimate of the total biomass of hardwood browse available to moose per hectare. Only those shrubs which had branches within moose browsing range were sampled. An estimate of browse consumed per hectare was obtained by multiplying the total browse available by the percentage of browsed twigs.

RESULTS AND DISCUSSION

The 8-year-old stand contained about 14,045 stems/ha (± 3,075, 95-percent confidence interval) with a maximum height of 4 m and the 15-year-old stand had 64,250 stems/ha (± 16,225, 95-percent confidence interval) with a maximum height of 7 m (table 1). Some plants had as many as five stems, each of which was counted separately. Current amounts of available hardwood browse in the 8-and 15-year-old stands were 37.88 and 113.00 kg/ha, respectively (table 1). Gasaway and Coady (1974) have estimated the mean consumption rate for an average adult moose to be 4 to 6 kg dry weight per day. Their estimate is based on energy requirements and utilization of digestible food. At a consumption rate of about 5 kg/moose/day, the forage available in the 8-year-old stand would support a maximum of 7.6 moose-days/ha (m-d/ha) and that in the 15-year-old stand 22.6 m-d/ha (table 2). Utilization estimates indicated only 21.4 and 62.2 kg/ha were consumed in the 8- and 15-year-old stands, respectively (table 1). This represents 4.3 m-d/ha in the 8-year-old stand and 12.4 m-d/ha in the 15-year-old stand.

Pellet group densities in the 8- and 15-year-old stands were 74 and 164 pellet groups/ha (p.g./ha), respectively, for the 1974-75 winter. A defecation rate on the two areas of 17.2 and 13.1 p.g./moose/day can be calculated by dividing the pellet groups per hectare by moose-days per hectare. Both figures are within the range of known defecation rates for moose and other ungulates (Julander et al. 1963, DesMueles 1968, Neff 1968).

Franzmann et al. (1976), working on the Kenai Peninsula in Alaska, has recorded a daily defecation rate for moose at 14.6 p.g./ha for females and 19.6 for males. His measurements were made by trailing moose for a 24-hour period and indicate exact figures as opposed to estimates. The results of my study, using an ingestion rate of 5 kg/moose/day, are closely correlated with these results. The moose studied on the Kenai Peninsula are confined to 1-mile-square enclosures and probably consume browse which they would not select if they were free moving. The moose in my study were feeding exclusively on new growth which is probably more digestible than the 2- and 3-year-old birch which moose on the Kenai were consuming. This could account for the lower defecation rates of moose in the interior. Alternatively, moose could be consuming slightly more than 5 kg/moose/day which would increase the estimate of daily defecation rates.

Browse utilization in the 8- and 15-year-old stands was 56 and 55 percent, respectively, for the 1974-75 winter (table 2). Data collected from a 3-year-old burn and a 70-year-old black spruce (*Picea mariana*) forest indicated browse utilization ranging from 8 to 44 percent (see footnote 2). In this study, amounts of available browse averaged 22.6 kg/ha in the burn and 9.9 kg/ha in the spruce stand. Milke (1969), using the clip, dry-weight method, recorded utilization of willow shrubs in the Tanana flats and foothills of interior Alaska of about 38 percent. In his study there were 204 kg of woody browse per hectare.

Table 1--*Production of available hardwood browse and consumption by moose on two Tanana flood plain study sites*

Species on study site	Diameter at point of browsing ($\bar{X}$ + S.E.)[1]	Weight per twig ($\bar{X}$ + S.E.)[1]	Twigs per stem ($\bar{X}$ + S.E.)[1]	Forage available per stem	Stems per hectare ($\bar{X}$)[1]	Browse produced	Browse consumed	Browse consumed
	- - - mm - - -	*- - g - -*		*- - g - -*		*kg/ha*	*kg/ha*	*Percent*
8-year-old stand:								
Salix alaxensis	3.88 ± 0.04	0.83 ± 0.02	3.81 ± 0.46	3.16	8,286	26.20	14.45	55
Salix interior	2.59 ± .04	.42 ± .01	3.71 ± .49	1.56	3,371	5.25	2.98	57
Populus balsamifera	4.05 ± .07	1.32 ± .02	2.04 ± .17	2.69	2,388	6.43	3.99	62
Total					14,045 (±3,075)[2]	37.88	21.42	56
15-year-old stand:								
Salix alaxensis	4.06 ± .14	.84 ± .02	2.42 ± .18	2.03	30,000	60.90	40.19	66
Salix novae-angliae	2.85 ± .08	.46 ± .01	2.83 ± .16	1.30	27,000	35.10	19.66	56
Salix monticola	2.85 ± .07	.46 ± .01	3.23 ± .25	1.49	2,250	3.35	.60	18
Populus balsamifera	4.07 ± .15	1.32 ± .02	2.07 ± .17	2.73	5,000	13.65	1.77	13
Total					64,250 (±16,225)[2]	113.00	62.22	55

[1]Mean ± 1 standard error.
[2]95-percent confidence interval.

Table 2--*Food carrying capacity of available hardwood browse and utilization by moose on two Tanana flood plain study sites.*

Study site	Carrying capacity[1]	Utilization	Available browse utilized	Pellet groups per day
	m-d/ha[2]	*m-d/ha*[2]	*Percent*	
8-year-old stand	7.6	4.3	56	17.2
15-year-old stand	22.6	12.4	55	13.1

[1]Carrying capacity is defined as the maximum number of days 1 moose can feed on the forage available on 1 hectare of habitat. Calculations are based on a consumption rate of 5 kg/moose/day (Gasaway and Coady 1974).
[2]Moose-day per hectare.

Moose normally consume several twigs with each bite. They also have a tendency to move slowly through a willow patch while feeding. When the available forage is reduced by 50 percent, the number of twigs per bite decreases. The moose then must move more and expend more energy to consume the same quantity of browse. It appears that when the available browse is reduced below a critical density, moose move on to a different area. The new browsing area often supports a different assemblage of plant species which, in turn, provides required diversity in the moose's diet. It is also interesting to note that 50-percent browse utilization may also maximize production of new hardwood browse the next growing season (Krefting et al. 1966 and references cited therein, Spencer and Chatelain 1953; also see footnote 2).

Some Salicaceae species are preferred over others. *Salix alaxensis* is the most common willow species present along the Tanana River and was one of the preferred forage species. *S. novae-angliae* was also common and heavily utilized in the 15-year-old stand. *S. interior* was also a preferred species but is less common. *S. monticola* was not as heavily browsed as the other willow species in the study area. Balsam poplar was heavily utilized in the 8-year-old stand, where it had a higher density and greater number of small branches within browsing reach, than in the 15-year-old stand. In the older stand, many of the trees were less accessible to moose due to larger stems and branches and heights of over 5 m. Alder, which was present at both sites, was not utilized as forage by moose. *Salix lasiandra* and *S. brachycarpa* were also present in low densities in both study areas but were not found in the study plots.

SUMMARY

Amounts of hardwood browse produced and consumption by moose were estimated in 8- and 15-year-old stands on the Tanana River flood plain near Fairbanks, Alaska. The total amounts of available hardwood browse produced in the two stands were 38 and 113 kg/ha, respectively. Of this, approximately 55 percent of available browse was consumed by moose in 1 year. The early successional stage plant communities on the Tanana flood plain provide an important winter habitat for moose.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

APR 27 19

PNW-268 January 1976

SILVICULTURAL AND DIRECT CONTROL OF MOUNTAIN PINE BEETLE IN SECOND-GROWTH PONDEROSA PINE

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ABSTRACT

In the first 5 years after treatment, silvicultural thinning reduced killing of *Pinus ponderosa* poletimber by *Dendroctonus ponderosae* by more than 90 percent and led to positive net stand growth in an eastern Oregon test. The felling and burning of infested trees also substantially reduced tree mortality caused by mountain pine beetle; even so, the treated stand declined in the post-treatment period due to damage by other agents. The practical effect of direct control in combination with thinning was no greater than that obtained by thinning alone.

KEYWORDS: Insect damage control (forest), Ponderosa pine, Pinus ponderosa, mountain pine beetle, Dendroctonus ponderosae, thinnings, fire use.

In the Northwestern United States, mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae), is the major pest of second-growth ponderosa pine, *Pinus ponderosa* Lawson. Outbreaks occur predominantly in poletimber, where stand density is high for a given site (Sartwell 1971). Beetle-killed trees, including ones with dominant positions in the forest canopy, characteristically have grown very slowly for more than 10 years prior to being attacked (Eaton 1941). Also, they have short crowns, typically less than one-third of tree height (Sartwell 1971). This evidence indicates that low tree vigor due to intensive between-tree competition underlies the occurrence of beetle outbreaks, and suggests silvicultural thinning as an approach to outbreak prevention.

Applied control efforts traditionally have aimed at the direct suppression of beetle populations by the felling and burning or insecticidal treatment of infested trees. However, the period of reduced tree killing obtained by direct control of *D. ponderosae* in *P. ponderosa* has not been documented.

We report here the 5-year results of a continuing study of indirect, direct, and combined methods for control of mountain pine beetle in second-growth ponderosa pine. Our objectives are to determine the degree and duration of reduced tree killing achieved by (1) different intensities of thinning, (2) felling and burning of infested trees, and (3) the treatment which combines suppressing the beetle population and then thinning the stand.

METHODS

The study area is located in the Sumpter Valley, about 25 km (15 mi) southwest of Baker, Oregon. The virgin pine forest here was heavily logged during the late 19th and early 20th centuries. A blanket of second-growth ponderosa pine now generally covers the lower slopes from the edge of the valley floor at 1200-m (4,000-ft) elevation to where the terrain steepens sharply at about 1500 m (5,000 ft). Severe tree killing by mountain pine beetle had occurred in the valley and vicinity for several years before the beginning of our test. In 1966, about 8000 ha (20,000 acres) were seriously infested.

The stand occupying the test site is nearly pure pine, with occasional pockets of western larch, *Larix occidentalis* Nuttall, and a few widely scattered Douglas-fir, *Pseudotsuga menziesii* (Mirbel) Franco. Stand structure is essentially even aged, and most trees were 10- to 20-cm (4- to 8-in) d.b.h. and about 55 years old when treatments were applied in 1967. Dominant trees then averaged about 12 m (40 ft) in height, indicating growth quality of the land rates as about Site Index 65 or Site Class V in the classification of Meyer (1961).

Experimental design consists of 10 plots, each covering about 10 ha (25 acres); these are grouped into two blocks (fig. 1). On the northern block, the beetle population was suppressed by the felling and burning of all infested trees during the late winter and early spring. Treated trees averaged 8.6/ha (3.5/acre). No direct control was applied against the beetle population in the southern block.

Plot assignments were randomly made within each block to obtain a double replication of these treatments: (a) unthinned check, (b) 3.5- by 3.5-m (12- by 12-ft) spacing between residual trees, (c) 4.5- by 4.5-m (15- by 15-ft), (d) 5.5- by 5.5-m (18- by 18-ft), and (e) 6.5- by 6.5-m (21- by 21-ft). These approximate

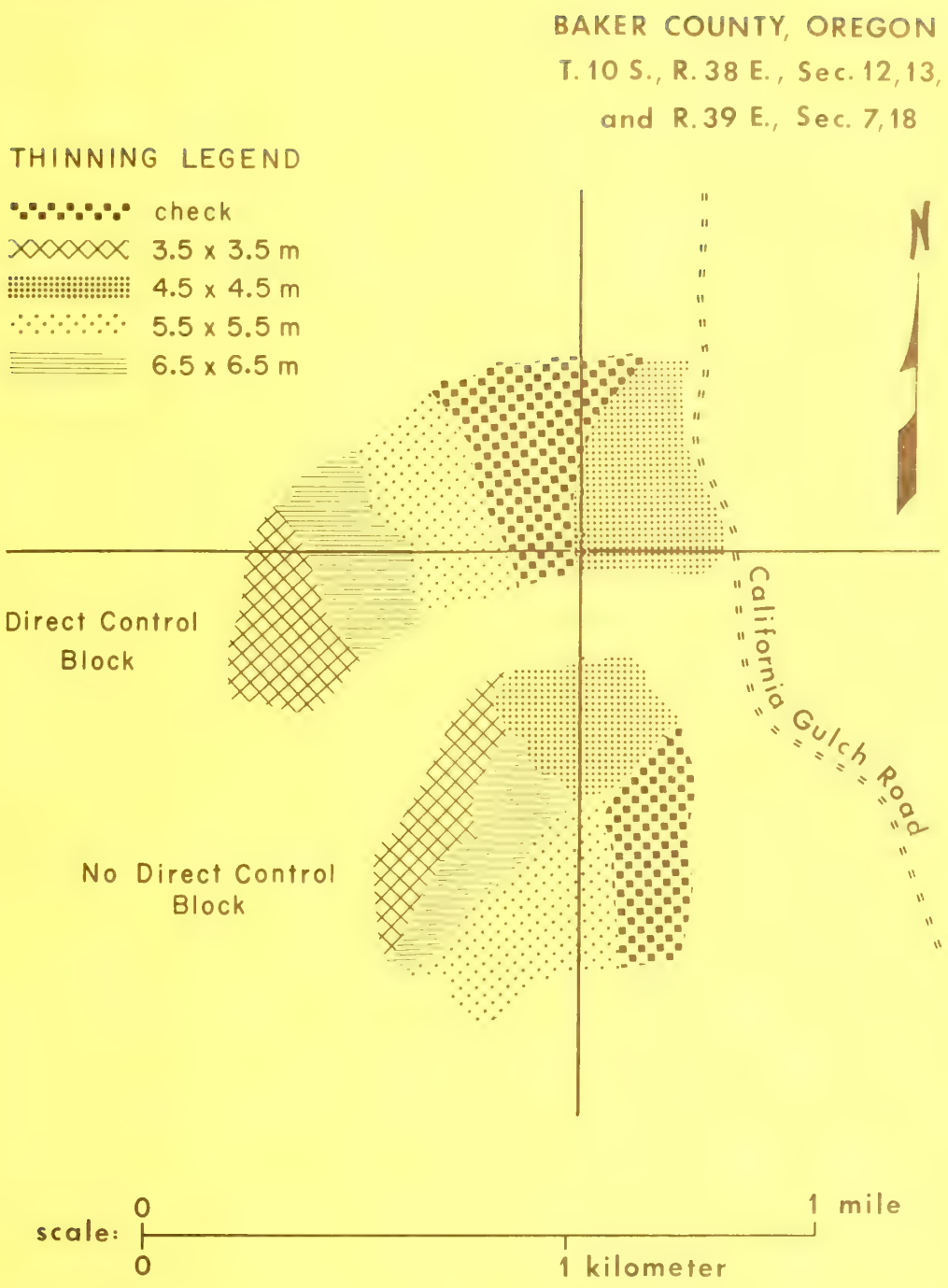

Figure 1.--Map of Sumpter Valley study area.

spacings were achieved by cutting the smaller trees in a way Smith (1962) referred to as a radical application of the low thinning principle. All cut trees were left where felled.

The point samping method (Beers and Miller 1964) was used to collect live stand and mortality data from 20 permanent sample points on each plot. The first live stand cruise was made in September 1967, the second in August 1972, and others are planned at 5-year intervals. We expect parts of the study to run for at least 20 years. Mortality cruises are conducted each year in late summer. Tallied dead trees are marked as to year and cause of death.

A full replicate of this test was installed contemporaneously in another area; but due to a misunderstanding, it was partially logged a year after treatment and rendered unsuitable for our experiment. Thus, lacking adequate replication for statistical analysis, we present our Sumpter Valley findings as a case history.

RESULTS

During the first 5 years after treatment, thinning substantially reduced tree mortality caused by mountain pine beetle and also led to positive net stand growth (table 1). Damage by this insect on the unthinned plots was at least 10 times greater than on the thinned plots. Nearly all tree killing by *Dendroctonus ponderosae* on the thinned plots occurred where thinning was lightest. The more heavily thinned plots were virtually free of damage by this beetle; indeed, they were rather free of mortality from all causes.

Table 1--*Cumulative tree mortality and net stand growth during 5 years after thinning*

Thinning treatment	1967 stand density	Loss by mortality cause			Net stand growth
		Beetle	Other	Total	
	Stem basal area, m^2/ha				
Unthinned	39.88	2.70	2.19	4.89	-4.78
3.5 by 3.5 m	26.87	.75	.63	1.38	-.63
4.5 by 4.5 m	19.74	.06	.06	.12	.75
5.5 by 5.5 m	14.22	.00	.17	.17	.69
6.5 by 6.5 m	8.06	.00	.17	.17	.52

Felling and burning of infested trees in 1967 substantially reduced tree killing by *D. ponderosae* in the 5 years after treatment (table 2).

Table 2--*Comparison of cumulative silvicultural and direct control effects 5 years after treatment*

Treatment	Loss by mortality cause		
	Beetle	Other	Total
	Stem basal area, m^2/ha		
Check	5.30	2.53	7.83
Direct control only	.11	1.84	1.95
Thinning only	.11	.35	.46
Direct control and thinning	.29	.17	.46

However, suppression of the beetle population did not lead to positive stand growth. Moderate mortality caused by root disease, snow breakage, competition, and *Ips pini* (Say) continued after the direct control treatment and resulted in stem basal area of live trees decreasing from 41.44 to 39.48 m^2/ha (180 to 172 ft^2/acre) during the 5-year posttreatment period.

Direct control applied preliminary to thinning had no measurable effect upon tree killing by mountain pine beetle in the 5-year posttreatment period. Thinning alone reduced *D. ponderosae*-caused mortality as much as did the combination of direct control plus thinning (table 2).

DISCUSSION AND CONCLUSIONS

Nearly 50 years ago, Munns and Colville (1928) remarked that no research had been done toward "determining the kind, quality and amount of thinning that should be given young 2nd-growth pine stands to make them fairly free from insect attach." Subsequently, there have been some advances in the silvicultural control of insects affecting mature trees. Most widely applied is the selective logging of old-growth ponderosa pine based on the scheme of Salman and Bongberg (1942) for rating tree susceptibility to attack by western pine beetle, *D. brevicomis* LeConte. However, thinning experiments to prevent insect damage in sapling and poletimber stands have been rare, even though authors of nearly all standard forest entomology textbooks mention the potential of thinning in pest management.

Our results from Sumpter Valley indicate that thinning is more than merely a potential means of dealing with mountain pine beetle in second-growth ponderosa pine. At least for the term of 5 years, its pest management value has been demonstrated on a near-operational scale. Thus, the main practical questions remaining are: (1) How many years will thinning prevent serious damage by the beetle? and (2) Do our results apply elsewhere in western North America? Also to be explained more fully is why thinning

reduces the effect of this insect on ponderosa pine stands.

We expect to continue our study for at least 20 years to determine duration of effectiveness for the different intensities of thinning. Evidence offers little reason to choose among the heavier thinnings, but it indicates the 3.5- by 3.5-m (12- by 12-ft) spacing will not have practical benefits, either entomologically or silviculturally, when applied after a beetle outbreak has begun. Light thinnings might be effective if made earlier in stand development than in our test, as Barrett (1968) obtained a good growth response with a 4.0- by 4.0-m (13- by 13-ft) thinning in a 47-year-old stand on Site Class V land in northern Washington. However, stand density at the time of treatment was much lower (stem basal area, 28 m^2/ha or 123 ft^2/acre) than in our test area (40 m^2/ha or 173 ft^2/acre.) Also, there was little beetle activity in the area when Barrett began his study.

Existing techniques for projecting stand development, such as those of Myers (1971) and Stage (1973), can provide interim answers about the duration of effectiveness for thinning as a pest control measure. When beetle population models are developed, they can be coupled with stand models to help determine probable effectiveness of treatment under various circumstances. However, knowledge of the practical value of thinning for management of mountain pine beetle in different areas and under various stand conditions must come primarily from field experiments and operational experience. A thinning test was begun in Montana in 1971, and another in the Black Hills of South Dakota is being contemplated. Although early results from Montana strongly support our findings, we urge establishment of tests in additional areas.

As to why thinning reduces tree killing by mountain pine beetle, we hypothesize that the removal of competing neighbors allows residual trees to increase their resistance to beetle attack. There is abundant silvicultural evidence that thinning improves the growth rate of individual trees, and we assume this sign of improved tree vigor is accompanied by a corresponding increase in attack resistance. After some years, we suggest, competition between trees will resume and ultimately will allow another beetle outbreak to occur. Thus, we also hypothesize that the heavier the thinning treatment the greater the period of reduced tree killing. Clearly, there is a need for physiological studies to determine how thinning affects tree resistance. Also needed are studies to identify the site resource for which between-tree competition is greatest.

An alternative or perhaps supplementary hypothesis, suggested by the work of Gara and Coster (1968) with *D. frontalis* Zimmerman, is that increasing the distance between trees reduces the probability that mass aggregation of beetles to one tree will result in neighboring trees being attacked. Our test evidence gives us no reason to challenge this notion; however, in several areas of the Pacific Northwest, we have observed substantial tree killing by *D. ponderosae* in mixed stands, where the ponderosa pines were spaced fairly widely but were stressed by competition from intermingling trees of nonhost species. Probably some distance between trees will prevent group killing, but how much has not been determined for mountain pine beetle.

Inadequate replication prohibits strong conclusions about the direct control aspects of our test, but the results raise doubts about the practical benefits gained by killing beetles

and their broods. The felling and burning of infested trees definitely reduced damage by the target pest during the 5-year posttreatment period. This finding agrees with operational experience that direct control is generally effective against *D. ponderosae* for about 3 to 7 years. However, as other mortality agents caused the stand to decline despite effective suppression of the beetle population, it is difficult to classify our direct control treatment as practically successful.

Possibly there are situations where the short-term effectiveness of direct control can be utilized in a stopgap action to provide time for a thinning program to be implemented. However, our findings suggest that suppression of a beetle population immediately prior to a scheduled thinning will not enhance overall control effectiveness: it merely increases treatment costs. Our findings are similar to those of J. W. Bongberg (see Miller and Keen 1960, p. 347-348), who found that a combination of direct and indirect methods was slightly more effective for control of *D. brevicomis* than a silvicultural method alone but not enough to justify the added costs.

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GPO 995-392

USDA FOREST SERVICE RESEARCH NOTE

PNW-269

February 1976

CUBIC-FOOT VOLUME TABLES AND EQUATIONS FOR YOUNG-GROWTH WESTERN HEMLOCK AND SITKA SPRUCE IN SOUTHEAST ALASKA

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by

Wilbur A. Farr, *Mensurationist*

and

Vernon J. LaBau, *Mensurationist*

ABSTRACT

Cubic-foot volume tables and equations are given for young-growth western hemlock and Sitka spruce, based on d.b.h. and number of logs to a merchantable top.

KEYWORDS: Western hemlock, *Tsuga heterophylla*, Sitka spruce, *Picea sitchensis*, volume tables (log), volume measurement (tree).

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

The cubic-foot volume tables presented here for young-growth (less than 150 years old) western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) supplement the tables presented in 1965 by Embry and Haack.[1/] They are based on d.b.h. (D) and log height (H) because timber cruisers in the Alaska Region generally estimate log heights instead of total height for sawtimber trees. The earlier tables did not contain cubic-foot volumes based on log heights.

METHODS

The basic data used to develop these cubic-foot tables consisted of measurements from 217 Sitka spruce and 160 western hemlock trees larger than 10.5 inches in diameter at breast height. Trees with diameters up to 38 inches for spruce and 26 inches for hemlock were used. Tree heights ranged from 51 to 170 feet for spruce and from 58 to 149 feet for hemlock.

Smalian's formula was used to compute cubic-foot volume for 16.3 foot logs[2/] between the top of the butt log and the 4-inch top, inside bark. For the butt log additional measurements were used so that its volume could be more accurately determined. In addition to measurements of inside bark diameter at the top and bottom of the log, measurements were also taken inside bark at breast height and at the midpoint of the log. The sum of the volumes of all the logs of a tree was the volume used to derive values in the tables.

Weighted linear regression was used to develop a volume prediction equation for each species. The model used was V=f(D,H), with each observation assigned a weight inversely proportional to observed $(D^2H)^2$. Weighting was accomplished by multiplying both sides of the model by $(D^2H)^{-1}$, giving the transformed model:

$$V(D^2H)^{-1} = f(D,H)(D^2H)^{-1}$$

where D = d.b.h., H = number of logs

The actual equation used in stepwise regression was:

$$\frac{V}{D^2H} = b_o + \frac{b_1}{D^2H} + \frac{b_2}{DH} + \frac{b_3}{H} + \frac{b_4}{D^4H}$$

and the final untransformed solutions were:

Spruce

$$V = 0.048534D^2H + \frac{507.72}{D^2}$$

Hemlock

$$V = 5.2132 + 0.045805D^2H$$

Cubic-foot volume tables prepared from these equations along with their precision are given in tables 1 and 2.

[1/] Embry, Robert S., and Paul M. Haack. 1965. Volume tables and equations for young-growth western hemlock and Sitka spruce in southeast Alaska. USDA For. Serv. Res. Note NOR-12, 21 p. North. For. Exp. Stn., Juneau, Alaska.

[2/] Includes 0.3-foot trim allowance.

Table 1--*Cubic-foot volumes (1-foot stump to a 4-inch top, d.i.b.) by d.b.h. and number of logs to a 40-percent top,*[1] *Smalian's formula, for young-growth western hemlock, southeast Alaska*[2]

D.b.h.[3] (inches)	Height (number of logs)[1]										Basis: trees measured[4]
	1	2	3	4	5	6	7	8	9	10	
11	10.8	16.3	21.8	27.4	32.9	38.5					17
12	11.8	18.4	25.0	31.6	38.2	44.8	51.4				30
13	13.0	20.7	28.4	36.2	43.9	51.7	59.4				19
14	14.2	23.2	32.1	41.1	50.1	59.1	68.1	77.0			9
15	15.5	25.8	36.1	46.4	56.7	67.0	77.4	87.7			18
16	16.9	28.7	40.4	52.1	63.8	75.6	87.3	99.0			20
17	18.5	31.7	44.9	58.2	71.4	84.6	97.9	111			8
18	20.1	34.9	49.7	64.6	79.4	94.3	109	124			15
19		38.3	54.8	71.4	87.9	104	121	138			8
20		41.9	60.2	78.5	96.8	115	134	152			6
21		45.6	65.8	86.0	106	126	147	167			4
22		49.6	71.7	93.9	116	138	160	183			1
23		53.7	77.9	102	126	151	175	199			0
24		58.0	84.4	111	137	164	190	216			1
25		62.5	91.1	120	148	177	206	234			3
26			98.1	129	160	191	222	253	284		1
27			105	139	172	206	239	272	306		0
28			113	149	185	221	257	292	328		0
29			121	159	198	236	275	313	352		0
30				170	211	253	294	335	376	417	0
31				181	225	269	313	357	401	445	0
32				193	240	287	334	380	427	474	0
33				205	255	304	354	404	454	504	0
34				217	270	323	376	429	482	535	0
35				230	286	342	398	454	510	566	0

[1] Number of 16.3-foot logs between 1-foot stump and a top equaling 40 percent of d.b.h., but not less than 6.0 inches inside bark.

[2] Based on weighted regression: $V = 5.2132 + 0.045805D^2H$. Standard error of estimate = 5.23 cubic feet or 7.28 percent of the mean volume.

[3] Diameter classes are midpoint; e.g., 11-inch class includes 10.6 to 11.5 inches.

[4] Number of trees; range of data for 160 trees enclosed by solid lines.

Table 2--*Cubic-foot volumes (1-foot stump to a 4-inch top, d.i.b.) by d.b.h. and number of logs to a 40-percent top,*[1] *Smalian's formula, for young-growth Sitka spruce, southeast Alaska*[2]

D.b.h.[3] (inches)	Height (number of logs)[1]										Basis: trees measured[4]
	1	2	3	4	5	6	7	8	9	10	
11	10.1	15.9	21.8	27.7	33.6	39.4	45.3				25
12	10.5	17.5	24.5	31.5	38.5	45.5	52.4				16
13	11.2	19.4	27.6	35.8	44.0	52.2	60.4				24
14	12.1	21.6	31.1	40.6	50.2	59.7	69.2	78.7			15
15	13.2	24.1	35.0	45.9	56.9	67.8	78.7	89.6			19
16	14.4	26.8	39.3	51.7	64.1	76.5	89.0	101			17
17	15.8	29.8	43.8	57.9	71.9	85.9	99.9	114			14
18	17.3	33.0	48.7	64.5	80.2	95.9	112	127			18
19	18.9	36.4	54.0	71.5	89.0	106	124	142			11
20	20.7	40.1	59.5	78.9	98.3	118	137	157			3
21	22.6	44.0	65.4	86.8	108	130	151	172			12
22		48.0	71.5	95.0	118	142	166	189			6
23		52.3	78.0	104	129	155	181	206	232		9
24		56.8	84.7	113	141	169	197	224	252		6
25			91.8	122	152	183	213	244	274		5
26			99.2	132	165	198	230	263	296		2
27			107	142	178	213	248	284	319		4
28			115	153	191	229	267	305	343		3
29			123	164	205	246	286	327	368		1
30				175	219	263	306	350	394	437	4
31				187	234	280	327	374	420	467	1
32				199	249	299	348	398	448	497	0
33				212	265	318	370	423	476	529	0
34				225	281	337	393	449	505	561	1
35				238	298	357	417	476	536	595	0

[1] Number of 16.3-foot logs between 1-foot stump and top equaling 40 percent of d.b.h., but not less than 6.0 inches inside bark.

[2] Based on weighted regression: $V = 0.048534D^2H + \frac{507.72}{D^2}$. Standard error of estimate = 7.51 cubic feet or 7.93 percent of the mean volume.

[3] Diameter classes are midpoint; e.g., 11-inch class includes 10.6 to 11.5 inches.

[4] Number of trees; range of data for 216 trees enclosed by solid lines. One tree not shown in the "Basis" column was in the 38-inch diameter class.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
USDA FOREST SERVICE RESEARCH NOTE

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BURYING FOREST RESIDUE--AN ALTERNATIVE TREATMENT

by

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and

Hugh R. McLean, *Forester*[1/]

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ABSTRACT

Burying forest residue in a mixed conifer stand which had been shelterwood cut was economical and effective. The fire hazard was reduced to an acceptable level and obstacles to future harvest operations were eliminated. This treatment also provided easy access for dispersed recreation and wildlife and eliminated a breeding ground for insects. The operation cost was about $83 per acre (1975 price). Burying is a residue treatment which can be used for shelterwood cut areas usually on a one-time basis only. Soils should be deep enough for pits 5 feet (1.5 m) in depth.

KEYWORDS: Slash disposal, forest residues.

[1/] Now with United Nations Food and Agriculture Organization, Nairobi, Kenya.

Even with today's improved utilization possibilities, timber harvesting practices continue to produce excessive accumulations of residue. Shelterwood cutting techniques in mixed conifer stands east of the Cascade Range in the Pacific Northwest are no exception. Residue accumulations may restrict dispersed recreational opportunities, act as a breeding ground for insects, impede movement of wildlife, and generally limit efficient forest management. These residues must be treated in some manner to eliminate obstacles to future harvest and to reduce the fire hazard.

If the benefits of shelterwood cutting are to be realized, harvested stands must be protected. One alternative may be to bury the residue within the harvested area. This paper reports the results of a study done to determine cost, time, and effect of burying forest residue.

Results of a feasibility study conducted in California (Schimke and Dougherty 1966) indicate that burying residue shows promise as a treatment for areas that are not too steep or rocky. Slash burying has also been used successfully as a disposal method on the Butte Falls Ranger District of the Rogue River National Forest in Oregon for many years. Roadside pits installed in 1961 showed no evidence of settling by 1975. A good grass cover has been reestablished, and mixed conifer reproduction, up to 4 feet (1.22 m) high, is growing on the pit sites.[2/]

STUDY PROCEDURE

The study was conducted on a 63-acre (25.5-hectare) area on the Sisters Ranger District of the Deschutes National Forest in Oregon which contained fairly homogeneous residue. The prevalent species was white fir (*Abies concolor* (Gord. & Glend.) Lindl.) with lesser amounts of ponderosa pine (*Pinus ponderosa* Laws.), larch (*Larix occidentalis* Nutt.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and western redcedar (*Thuja plicata* Donn) on deep, sandy loam soil. The slope ranged from 0 to about 10 percent.

A line transect method of sampling was used to determine the amount of residue (Van Wagner 1968). A 3,000-foot (914.4-m) continuous transect line was used with a new random azimuth chosen for each 100-foot (30.48-m) segment.

Residue volume was determined by using the equation:

$$V = \frac{373.3092\ \Sigma d^2}{L}$$

where:

V = volume in cubic feet per acre
d = diameter of pieces of residues in inches
L = length of total transect line in feet

The equation used for finding residue weights was:

$$W = \frac{11.65\ S\ \Sigma d^2}{L}$$

where:

W = weight of residue in tons per acre
S = specific gravity (0.42 was used for this study).

[2/] Rambo, Ira. 1975. Personal conversation. U.S. Dep. Agric., For. Serv., Butte Falls Ranger District, Butte Falls, Oreg.

Pit locations were selected that would permit excavation with little or no bole injury or result in excessive root damage to residual trees. A Caterpillar D7E[3/] tractor was used to dig the pits and a Case 1150 tractor to push the residue into them and to cover each with at least 2 feet (0.6 m) of soil. The time required for each operation and costs were recorded.

Rate of fire spread and resistance to control conditions were determined for the area as a whole before and after treatment. The fuel type identification system of the Pacific Northwest Region of the U.S. Forest Service (U.S. Department of Agriculture, Forest Service 1968) was used to determine the relative degree of fire hazard and its reduction due to burying the residue. In this system, fuels are classified by one of four rate-of-spread and one of four resistance-to-control categories, making 16 possible fuel type combinations. The four categories in both classifications are extreme (E), high (H), moderate (M), and low (L). The hazard rating was based on observations made from several points within the study area.

The general condition of trees which had sustained root or bole damage or both was evaluated immediately after the pits were dug and 3-1/2 years after treatment. They were rated as either in good (green and vigorous looking) or poor (excessive dead needles or appeared to be much less vigorous) condition or as dead. The study area was broadcast seeded with grass.

In 1973, 3 years after treatment, a forest pathologist examined damaged trees adjacent to two selected pits and exhumed residue from those pits to determine if burying residue had caused the appearance of forest disease, especially that of root rot. One pit was on a well-drained site and the other on a poorly drained site. Disks 2 inches (5.08 cm) thick were cut from pieces of residue collected from the pits and from the boles of selected standing live trees. Pieces cut from the disks were incubated in either moist sand to test for *Armillaria mellea* or on wet paper towels to test for the *Oedocephalum* stage of *Fomes annosus*.[4/]

Two healthy trees adjacent to the two pits were pushed over with a tractor to permit examining roots broken at the time of residue burial. Also, the general biological condition of each pit was observed.

RESULTS

There were 3,863 cubic feet per acre (270.3 m^3/ha), or about 51 tons per acre (114.3 metric tons/ha), of down and dead residue in the study area before burying took place. Although the residue ranged from 2 to 32 inches (5.1 to 81.3 cm) in diameter, about 90 percent of the material was 10 inches (25.4 cm) or less. The average was about 5 inches (12.7 cm). The arrangement and quantity were rated as HH fire hazard. Burying reduced the surface residue by 80 to 90 percent, lowering the fire hazard to ML. This rating was considered an acceptable hazard level. Pushing the residue to the pits scarified the ground, resulting in bare soil on practically the whole area (fig. 1).

[3/] Mention of product or trade names does not imply endorsement by the U.S. Department of Agriculture.

[4/] Roth, Lewis F. 1973. Pathological implications of forest residue disposed by burial and by prescribed burning. Unpublished manuscript on file at U.S. Dep. Agric., For. Serv., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Figure 1.--Three views of a mixed conifer stand which has been shelterwood cut: left, before burying logging residue; right, after burying logging residue.

The D7E tractor required 45 hours to dig 72 pits in the 63 acres (25.5 ha). The pits were 10 feet (3.1 m) wide and 5 feet (1.5 m) deep. The length ranged from 20 to 111 feet (6.1 to 33.8 m) and averaged 62 feet (18.9 m). The average time to dig a pit was 38 minutes. The soil was fairly deep and not rocky so no difficulties were encountered.

Pushing the residue into the pits and covering with at least 2 feet (0.6 m) of soil took the Case 1150 tractor about 124 hours, or 1.7 hours per pit (fig. 2). The operator and helper each worked 153 hours.

Figure 2.--Burying the residue with a tractor.

The D7E tractor and operator were rented for $25 per hour (1970 price). The Case 1150 was owned by the Ranger District and cost $3.50 per hour (1970 fixed and operating costs). Operator and helper wages for the Case 1150 totaled $7.68 per hour. Total cost per acre for digging the pits and burying the residue was $43.40 ($107.24/ha). At 1975 prices, the cost would increase to about $83 per acre ($205.09/ha).

The condition of 36 trees was observed: 24 were rated in good condition 3-1/2 years after sustaining root or bole damage or both, 9 trees were dead with only 2 still standing, 2 had been knocked askew, and 1 had a broken top.

No serious endemic root diseases were found. Only one large stump was infected by *Phellinus (poria) weirii*. There was almost no evidence of root pathogens found from samples incubated in moist sand. Out of 239 chips, 2 produced *Oedocephalum* type of growth that could have been the conidial stage of *Fomes annosus*. These chips were from samples taken from aboveground scars on white firs. Rhizomorphs of the *Armillaria* type were found on one of 72 samples tested for *Armillaria mellea*. The rhizomorphs observed were atypical and could have been produced by a fungus other than *Armillaria* (see footnote 4).

Decay by saprophytes was taking place in both pits. Material 1/2 inch (1.27 cm) or less in diameter was completely decayed and absent in the pits. All buried sapwood was in advanced stage of decay. Heartwood decay was progressing, largely due to heart rot activity in logs culled because of trunk rot. No fruiting bodies, rhizomorphs, or other identifiable structures of root pathogens were found in material from the pits.

Very little vegetation had grown on those pits where topsoil was mixed with subsoil. On a few of the pits, the topsoil was not mixed with the subsoil

when replaced; these areas had grass growing on them. Grass and forbs were growing in adjacent areas.

DISCUSSION AND CONCLUSIONS

Burying residue in the study area was effective in reducing the fire hazard to an acceptable level and eliminating obstacles for future harvest operations. It also provided easy access for dispersed recreation activities and wildlife and eliminated a breeding ground for insects.

This residue treatment was efficient and economical. It required about 19 working days (8-hour) to treat 63 acres (25.5 ha) which had about 51 tons per acre (114.3 metric tons/ha) of residue. The cost was about $83 per acre ($205.09/ha) (1975 price).

Scarring of standing trees occurred. This can provide entry courts for butt rots which are capable of killing injured trees and spreading through the roots to other trees. This is particularly true for the nonresinous species such as white fir which was prevalent in this study area. Douglas-fir and ponderosa pine are less susceptible to entry of fungi following mechanical injury. Also, if care is taken not to scar the standing trees, a general weakening of physiological defenses is unlikely.

Trees in the area appeared healthy with little mortality after 3-1/2 years.

Almost all the area was scarified by the operation; however, erosion did not present any problems because of stable soils and gentle slopes. Vegetation did grow back, mainly grasses and forbs, but was very sparse or nonexistent on the pits. This could present problems on erodible soils. Also, the area covered by pits was not productive except where care was taken to replace topsoil; then grasses did well. This amounted to about 1 acre (0.4 ha), or 1.6 percent of the total area. This concurs with work performed in 1973[5/] when slash from ponderosa pine thinning was buried on the Deschutes National Forest using techniques similar to those in this study. The only difference was that the topsoil was removed from each pit, stockpiled, then replaced when the pits were covered. Grass seed was subsequently drilled on all disturbed areas which resulted in the establishment of a good stand of grass.

Burying is a residue treatment which can be used for some shelterwood cut areas. However, one must keep in mind that in most cases this treatment could be used only once for a particular area, depending on the number of pits needed and space between pits. Another method would have to be used if future treatment is necessary for that area. Also, soils should be deep enough for pits 5 feet (1.5 m) in depth.

[5/] Foster, William. 1974. Personal conversation. U.S. Dep. Agric., For. Serv., Sisters Ranger District, Sisters, Oreg.

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USDA FOREST SERVICE RESEARCH NOTE

PNW-271

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RESPONSE OF *PENSTEMON FRUTICOSUS* TO FERTILIZATION

by

G. O. Klock, *Research Soil Scientist*

ABSTRACT

Bush penstemon (*Penstemon fruticosus* (Pursh) Greene), an attractive ground cover on east Cascade slopes, appears to survive under low fertility, xeric conditions. These plant characteristics are desirable for revegetating severely disturbed areas. Seedling response to fertilization was tested to find if growth rates could be increased to provide quicker ground cover with new plantings. Bush penstemon does respond to nitrogen and phosphorus fertilization under greenhouse conditions. It appears that, with adequate soil moisture, 50- to 100-ppm nitrogen is sufficient for nearly maximum growth response.

KEYWORDS: Nitrogen fertilizer response, fertilizer (inorganic) (-nursery beds, growth regulators (applied), erosion -)vegetation.

INTRODUCTION

Bush penstemon (*Penstemon fruticosus* (Pursh) Greene) is an attractive native ground cover frequently found on recently logged areas and new roadbank cuts on the east slopes of the Cascade Range in Washington. It is easily identified by its brilliant blue-lavender to light-purplish flowers[1/] in the early spring. One of bush penstemon's characteristics which makes it useful for stabilization of severely disturbed soils is its apparent ability to survive under low fertility, xeric conditions. The plant reproduces by seed and spreads across open ground by prolific layering. Rate of spreading is relatively unknown, although it appears to be quite slow. Since the most frequent observations of the plant are on poor soils such as roadbanks, it appears fertilization could hasten vegetative growth, which is highly desirable for early soil surface protection to reduce erosion. Although the plant appears to be a pioneering species, it is not known to have the ability to fix nitrogen by the symbiotic process. Therefore, a greenhouse fertilization study was initiated to determine the plant's vegetative response to applied fertilizers.

THE STUDY

To reduce the length of time necessary for the study and to maintain homogeneity of plant material, cuttings were taken in the late fall from a large plant colony on a roadbank cut near Blewett Pass, west of Wenatchee, Washington. These cuttings, approximately 12 cm long with all leaves removed except the upper two, were placed in damp vermiculite and kept in a cool corner of the greenhouse out of direct sunlight. After 1 month, a prolific set of roots up to 5 cm long was observed for about 90 percent of the cuttings. The newly rooted plants were transferred to 16.5-cm plastic pots, where a mixture of 25-percent sand, 25-percent peat, and 50-percent silt was used as the rooting medium.

After planting the newly rooted cuttings, the pots were saturated with distilled water and allowed to drain for 24 hours. After drainage, each pot was weighed. Distilled water was added twice a week to return the pot to its original drained weight. No drainage water which could contain plant nutrients was allowed to escape after the initial watering. Night temperatures in the greenhouse were kept at 18 ^{o}C and daytime, at 23 ^{o}C or above, depending on the ability of the greenhouse air conditioning to meet the summer heat load. Artificial light was used to keep a minimal photoperiod of 15 hours.

After 6 weeks of growth following transplanting, the plants were divided into five groups according to plant size. Each group was used for an experimental replication (blocks). Plant height and leaf area (horizontal surface cover) were measured on each plant. Leaf area was measured with a 6.35-mm grid counter. Similar measurements were made at the completion of the experiment to evaluate vegetative plant response to fertilization.

The fertilizer treatments used in a four-factor (2 x 2 x 2 x 4) experiment in randomized blocks were four levels of nitrogen (0, 75, 150, and 300 ppm),

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[1/] Hitchcock, C. L., A. Cronquist, M. Ownbey, and J. W. Thompson. 1959. Vascular plants of the Pacific Northwest. Pt. 4. Univ. Wash. Publ. Biol., Seattle.

two levels of phosphorus (0 to 100 ppm), two levels of potassium (0 and 100 ppm), and two levels of sulfur (0 and 100 ppm). Sources of fertilizer materials were treble-superphosphate, potassium chloride, calcium sulfate, and urea. All fertilizer was broadcast on the soil surface and mixed into the surface soil.

RESULTS

Plant growth response to fertilization in terms of increased height and leaf area was measured after a 90-day test period. Leaf area was not a good indicator of response because of large differences in plant form. Increases in height were also affected by plant form, although not to the extent observed for leaf area. The correlation between increased plant height and leaf area for the test period was 0.61. Plant response as measured by height for the fertilizer treatments is shown in table 1.

Table 1--Height growth response of *Penstemon fruticosus* to 4 levels of nitrogen, 2 levels of phosphorus, 2 levels of potassium, and 2 levels of sulfur fertilizer application (in mm per potted plant)

Nutrient	Level of application	Nitrogen (ppm)				
		0	75	150	300	Mean
	ppm	- - - - - - - - - *mm* - - - - - - - - -				
Phosphorus (P_2O_5)	0	10.3	33.9	31.2	24.5	25.0
	100	15.1	33.7	44.9	33.0	31.7
Potassium (K_2O)	0	16.0	33.5	42.3	34.0	31.5
	100	9.5	34.1	33.7	23.5	25.2
Sulfur (SO_4)	0	15.5	33.4	42.4	28.2	29.9
	100	10.0	34.3	33.7	29.3	26.8
Mean	--	12.7	33.8	38.0	28.8	28.3

Increase in plant height as a response to nitrogen fertilizer was significant at the 1-percent level and to phosphorus at the 5-percent level. No other fertilizer treatments were significant. Plant response to nitrogen increased up to the 150-ppm treatment and then decreased at the 300-ppm level. It appears that high rates of nitrogen fertilization, even with sufficient availability of other plant nutrients, will reduce penstemon growth under greenhouse conditions. The largest treatment response was to the initial 75-ppm nitrogen, which increased plant height 166 percent. Phosphorus at the 100-ppm level increased height by 26.8 percent. Available nutrients in the potting soil may have been sufficient to meet low plant requirements for potassium and sulfur fertilization.

CONCLUSION

Bush penstemon does respond to nitrogen and phosphorus fertilization under greenhouse conditions. It appears that 50- to 100-ppm nitrogen, when soil moisture is adequate, provides near maximum growth response. Plant requirements for potassium and sulfur appear to be quite low. However, on severely disturbed subsoils with extremely low fertility, bush penstemon may be expected to show increased growth response to low levels of potassium and sulfur fertilization. Field testing is necessary to confirm these greenhouse experimental results.

* * * *

GPO 995-826

ALASKA OREGON WASHINGTON
PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

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CHARACTERISTICS OF RESIDUES IN A BALLOON LOGGED AREA OF OLD-GROWTH DOUGLAS-FIR

by

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ABSTRACT

The volume and character of residues in a 44-acre old-growth Douglas-fir stand in the Oregon Cascades were determined before and after the area was clearcut and balloon logged.

The gross volume of residues on the ground increased from 5,585 cubic feet per acre before logging to 8,539 cubic feet after logging--a 53-percent increase. Not all size categories of residues increased in volume, however; a noticeable decrease was recorded in larger diameter classes, indicating some utilization of prelogging residues.

Usable residues are defined as material which can be yarded without breaking up, at least 10 percent sound 3 inches and greater in diameter, and at least 4 feet long. According to these specifications, more than 80 percent of the prelogging residues and nearly 70 percent of the logging residues could have been used.

Average soundness of the usable prelogging residues was 44 percent and 76 percent for the logging residues. A fourfold increase in piece count of these residues was recorded after logging. Most of this increase occurred in small diameter classes of residues.

More than half the usable residues was from felled trees. Bucked pieces were recorded with greater frequency in the postlogging residues than in the prelogging residues. Over 45 percent of the residues had been bucked. The larger and sounder portion could have been used if the bucking procedure had been modified.

KEYWORDS: Slash -)balloon logging, slash utilization, residue, wood waste utilization.

REST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

INTRODUCTION

The Pacific Northwest Forest and Range Experiment Station is conducting studies of three timber sale areas within the Pansy Creek drainage on the Estacada Ranger District of the Mount Hood National Forest in Oregon. These sales were designed to accomplish certain land management goals through use of three aerial logging systems--balloon, helicopter, and skyline. The aim of the studies is to evaluate the performance of the systems in attaining land management objectives. Aerial logging with balloon, helicopter, or skyline systems can substantially reduce the environmental impact of more conventional logging systems. The steep slopes, wet soil, streamside areas, fragile soils, and uneven terrain conditions in the sale areas all require special effort if merchantable timber is to be harvested without undesirable effects.

Residues left after logging are an important factor when the performance of the logging system in attaining land management objectives is evaluated. The land manager is faced with the problem of managing these residues to achieve optimum utilization of the resource, to minimize the risk of fire, and to achieve rapid regeneration in a manner that meets a wide range of environmental requirements for multiple-use forestry.

The aim of this report is to indicate the quantities and characteristics of residues left in an area logged by a balloon system. The main emphasis is on the utilization potential of the residues. The report is directed to those who are concerned with reducing logging residue to improve forest land management--either through removal for use as additional raw material or through onsite treatment.

SCOPE AND PROCEDURE

This report is based on an inventory of residues on a 44-acre area that was clearcut and logged by a balloon inverted skyline system.[1/] The Forest Service timber sale contract specifications for the study area required that all logs one-third sound with a minimum net scale of 80 board feet be removed. These specifications were applicable only to logs 6 inches and larger in diameter and at least 8 feet long. Terrain on the study area was primarily steep and broken, with the slope varying from 10 to 90 percent. Old-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) was the principal species in the timber stand (about 76 percent by volume). Secondary species included western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western redcedar (*Thuja plicata* Donn), and noble fir (*Abies procera* Rehd.). The timber sale cruise estimated the average net merchantable stand volume to be about 43,000 board feet per acre.

Volume and character of the residue on the study area were determined before and after harvesting activities by a line intersect method of sampling.[2/] [3/]

[1/] Dykstra, Dennis P. 1974. The Pansy Basin study. Comparing yarding rates and costs for helicopter, balloon and cable systems. *In* Loggers handbook, vol. 34, p. 20-23, 158-164, 176-178. Pac. Logging Congr., Portland, Oreg.

[2/] Warren, W. G., and P. F. Olsen. 1964. A line intersect technique for assessing logging waste. For. Sci. 10(3):267-276.

[3/] Van Wagner, C. E. 1968. The line intersect method in forest fuel sampling. For. Sci. 14(1):20-26, illus.

Only material on the ground was recorded; standing (live or dead) material was not tallied. The residue remaining after logging was sampled before any slash disposal treatment. The line intersect method used a systematic grid-point sampling design, with random orientation of 200-foot line segments at each grid point.[4/] Before and after logging, 80 line segments were located in the study area.

All residues 3 inches and greater in diameter at the point of intersection with the transect line were tallied. The 3-inch limit was based on what was considered to be a reasonable expected limit of utilization. Each piece was tallied by species, size, soundness, and material handling class. Diameter inside bark of each piece to the nearest inch at the point of crossing the transect line was recorded. Length (to a 3-inch diameter) to the nearest foot was recorded for all residue pieces 4 feet long or longer; a record of length for shorter pieces was not kept. Slabs from shattered trees were also recorded if the thickness plus width of the piece averaged 3 inches or greater; both thickness and width were recorded.

Soundness (proportion of wood usable for pulp chips--also known as firmwood) was recorded to the nearest 10 percent at the point of intersection. Estimates of soundness were based on the estimated proportion of the cross-sectional area that was sound and usable for pulp chips. Material decayed or excessively splintered was considered unusable. Where the cross-sectional area could not be seen, soundness at the transect point was estimated by viewing both ends of the piece.

In addition to records of coarse residues, a tally of the finer residues (fuels) was also made.[5/] This tally included material from 0.26 to 1.0 inch in diameter in the first 6 feet of the transect line and 1.1 to 2.9 inches in diameter in the first 10 feet of the line.

During inventory of the logging residues, each piece of coarse residue was also classified into five material handling categories. Pieces too decayed, splintered, or short (less than 4 feet) to be considered usable were classed as fuel; all others were placed in one of the following categories:

1. From a felled tree and bucked on at least one end.
2. From a felled tree and broken on both ends.
3. From prelogging (natural) residue; i.e., from dead and down windthrows, etc., and bucked on at least one end.
4. From prelogging residue and broken on both ends.

[4/] Howard, James O., and Franklin R. Ward. 1972. Measurement of logging residue--alternative applications of the line intersect method. USDA For. Serv. Res. Note PNW-183, 8 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

[5/] Fosberg, Michael A., and John E. Deeming. 1971. Derivation of the 1- and 10-hour timelag fuel moisture calculations for fire-danger rating. USDA For. Serv. Res. Note RM-207, 8 p., illus. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

RESULTS

Logging Increased Residue Volume

The gross volume of all residues on the ground before logging averaged 5,585 cubic feet per acre. After logging, the volume estimate was 8,539 cubic feet per acre--a 53-percent increase. The volumes of residue before and after logging in various diameter classes are presented in table 1.

Table 1.--*Average gross volume of residues before and after logging, by diameter class, Pansy Creek balloon logging sale*

Diameter class (inches)	Gross volume of residues	
	Before logging[1/]	After logging[2/]
	- -Cubic feet per acre- -	
0.26- 1.0	129.5	300.8
1.1 - 2.9	267.3	648.2
3.0 - 4.4	126.6	261.2
4.5 - 7.4	186.8	613.2
7.5 -10.4	363.3	700.7
10.5 -13.4	432.4	730.4
13.5 -16.4	360.5	821.2
16.5 -19.4	254.5	505.6
19.5 -22.4	529.2	757.2
22.5 -25.4	433.6	514.9
25.5 -28.4	300.8	674.7
28.5 -31.4	439.4	376.8
31.5 -34.4	185.6	275.3
34.5+	1,553.8	863.9
Slabs	22.2	494.6
Total	5,585.5	8,538.7

[1/] Dead and down material which includes material not yardable, less than 10 percent sound, and less than 3 inches in diameter and 4 feet long.

[2/] All down material which includes material not yardable, less than 10 percent sound, and less than 3 inches in diameter and 4 feet long.

The diameter classes of 28.5 to 31.4 inches and 34.5 inches and larger were exceptions to the general increase in residues volume. Utilization of the prelogging residues in these diameter classes apparently exceeded the volume generated in harvesting. This was especially true of the 34.5-inch and larger material.

The gross volume of logs removed during the balloon logging operation, as tallied at the truck scale station, was 9,825 cubic feet per acre. This is comparable to the volume of material 8,539 cubic feet, left on the ground as residue.

Utilization Potential of Residues

The portion of the total residue volume that has some potential for utilization is defined as material which can be yarded without breaking up and is at least 10 percent sound, 3 inches and greater in diameter, and at least 4 feet long. According to these specifications, 4,651 cubic feet per acre--about 80 percent of the prelogging residue--(coefficient of variation of 78.3 percent) could be utilized. A breakdown of this volume by diameter and length classes is contained in table 2. Some of these natural residues were salvaged during the harvesting operations. The marked reduction in the residue volume in the large size categories is due to utilization of the larger and sounder portions of the prelogging residues.

It should be noted that the harvesting activities reduced the utilization potential of the natural residues. Many pieces were broken and shattered when the standing trees were felled and yarded. The large increase in slab volume after logging (table 1) indicates considerable shattering occurred during the harvesting operations. About 90 percent of the slabs were not usable.

Much of the prelogging residue was defective. The average soundness of usable prelogging residues was 44 percent compared with 76 percent for logging residues. Removal of the larger and sounder prelogging residues during the logging operation reduced, to some extent, the average soundness of the logging residue. The species composition and soundness data of the usable residues before and after logging are presented in tables 3 and 4.

About 70 percent, or 5,974 cubic feet per acre (coefficient of variation of 55.2 percent) of the logging residues, had utilization potential according to the study specifications. The remaining 2,565 cubic feet of residue (difference between 8,539 (table 1) and 5,974 cubic feet per acre) did not meet these specifications. The average gross and net volumes of usable logging residue are shown by soundness and by diameter and length classes in table 5.

A fourfold increase in the usable residues piece-count per acre was recorded after logging. Most of this increase occurred in the small diameter classes of residue. The number of pieces of usable residue per acre before and after logging by soundness and by diameter and length classes is summarized in tables 6 and 7.

Logging residues that are at least 50 percent sound, 8 inches and greater in diameter, and at least 14 feet long averaged 2,815 cubic feet per acre and comprised almost half the usable residues. These residues would probably meet or exceed pulp or utility log specifications. This volume is in 103 pieces per acre, which is slightly less than 10 percent of the 1,077 pieces of residue on the average acre.

More than half the gross volume of usable logging residue was from felled trees. Of this amount, more than half had been bucked from longer pieces. For the previously down residue remaining on the logged area, less than half had been bucked from longer pieces. The volume of usable logging residue by soundness and material handling class is presented in table 8.

Over 45 percent of the usable residue volume was recorded as having been

Table 2.--*Average gross and net volumes of usable prelogging residue by diameter and length classes, Pansy Creek balloon logging sale*[1/]

Diameter class (inches)	All classes		Length class (feet)							
			4.0-7.9		8.0-13.9		14.0-20.9		21.0+	
	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net
	Cubic feet per acre									
3.0- 4.4	47.2	36.7	15.2	11.0	14.8	11.3	9.5	8.0	7.6	6.4
4.5- 7.4	141.2	99.7	10.8	4.4	34.1	21.8	27.0	19.7	69.2	53.8
7.5-10.4	323.4	199.4	43.0	19.7	25.1	12.4	73.6	28.7	181.6	138.6
10.5-13.4	365.2	190.2	27.6	1.0	21.9	12.8	86.4	34.2	229.3	142.2
13.5-16.4	294.6	174.6	10.6	6.4	11.9	1.2	71.6	28.2	200.5	138.8
16.5-19.4	254.5	132.8	22.6	0	22.6	3.0	89.9	42.2	119.4	87.6
19.5-22.4	446.7	186.3	9.4	5.6	41.2	12.4	97.7	31.3	298.4	137.0
22.5-25.4	433.6	190.0	26.8	1.4	42.6	8.3	70.6	21.1	293.6	159.2
25.5-28.4	227.6	98.5	0	0	36.6	11.0	52.4	8.9	138.8	78.6
28.5-31.4	355.5	99.3	42.0	8.4	84.0	13.6	63.0	23.1	166.6	54.2
31.5-34.4	185.6	64.9	0	0	27.0	10.8	0	0	158.7	54.1
34.5+	1,553.8	572.5	30.2	3.0	0	0	303.9	90.3	1,219.6	479.2
Slabs	22.2	2.3	3.2	.4	19.0	1.9	0	0	0	0
Total	4,651.1	2,047.2	241.4	61.3	380.8	120.5	945.6	335.7	3,083.3	1,529.7

[1/] Includes all dead and down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, at least 10 percent sound, and yardable.

Table 3.--*Average gross and net volumes of usable prelogging residue by species, Pansy Creek balloon logging sale*[1/]

Species	Gross volume	Net volume	Soundness	Proportion of total
	Cubic feet per acre		- - - *Percent* - - -	
Douglas-fir	2,256.2	821.0	36.4	48.5
Hemlock	1,173.2	520.2	44.3	25.2
Cedar	1,082.4	613.4	56.7	23.3
Pines	5.9	3.2	54.2	.1
Other softwoods	133.4	89.4	67.0	2.9
Hardwoods	0	--	--	--
Total or average	4,651.1	2,047.2	44.0	100.0

[1/] Includes all dead and down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, at least 10 percent sound, and yardable.

Table 4.--*Average gross and net volumes of usable logging residue by soundness and species, Pansy Creek balloon logging sale*[1/]

Percent soundness and species	Gross volume	Net volume	Soundness	Proportion of total
	Cubic feet per acre		- - - - *Percent* - - - -	
75+ percent sound:				
Douglas-fir	1,897.4	1,768.9	93.2	51.8
Hemlock	612.3	597.4	97.6	16.7
Cedar	1,096.2	1,053.6	96.1	30.0
Pines	23.5	23.5	100.0	.6
Other softwoods	27.8	27.8	100.0	.8
Hardwoods	1.7	1.7	100.0	0
Total or average	3,658.9	3,472.9	94.9	[2/]99.9
50+ percent sound:				
Douglas-fir	2,672.6	2,236.2	83.7	54.2
Hemlock	729.0	671.0	92.0	14.8
Cedar	1,453.0	1,281.5	88.2	29.4
Pines	49.0	38.2	78.0	1.0
Other softwoods	27.8	27.8	100.0	.6
Hardwoods	1.7	1.7	100.0	0
Total or average	4,933.1	4,256.4	86.3	100.0
30+ percent sound:				
Douglas-fir	3,054.9	2,370.6	77.6	55.6
Hemlock	773.9	687.4	88.8	14.1
Cedar	1,565.0	1,323.4	84.6	28.5
Pines	67.4	45.5	67.5	1.2
Other softwoods	27.8	27.8	100.0	.5
Hardwoods	1.7	1.7	100.0	0
Total or average	5,490.7	4,456.4	81.2	[2/]99.9
10+ percent sound:				
Douglas-fir	3,490.3	2,445.8	70.1	58.4
Hemlock	783.1	689.2	88.0	13.1
Cedar	1,591.4	1,328.4	83.5	26.6
Pines	78.0	47.6	61.0	1.3
Other softwoods	29.2	27.8	95.2	.5
Hardwoods	1.7	1.7	100.0	0
Total or average	5,973.7	4,540.5	76.0	[2/]99.9

[1/] Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

[2/] Total does not equal 100 because of rounding.

Table 5.--*Average gross and net volumes of usable logging residue by soundness and by diameter and length classes, Pansy Creek balloon logging sale*[1/]

Percent soundness and diameter class (inches)	All classes		Length class (feet)							
			4.0-7.9		8.0-13.9		14.0-20.9		21.0+	
	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net
	Cubic feet per acre									
75+ percent sound:										
3.0- 4.4	235.6	232.2	102.3	100.4	67.7	66.8	42.2	42.1	23.3	22.8
4.5- 7.4	523.0	512.6	111.2	108.6	99.3	97.1	162.8	159.8	149.6	147.0
7.5-10.4	522.3	505.4	65.0	63.0	136.2	132.6	154.8	150.4	166.2	159.3
10.5-13.4	476.9	457.0	66.5	64.6	90.9	85.0	162.6	157.0	157.0	150.4
13.5-16.4	456.9	438.4	95.6	94.2	62.5	59.8	129.4	124.6	169.4	159.9
16.5-19.4	251.8	233.8	52.6	50.4	57.9	55.2	73.8	66.2	67.4	62.0
19.5-22.4	314.8	298.0	28.5	28.5	79.4	72.6	106.3	100.6	100.6	96.4
22.5-25.4	171.8	160.0	25.5	22.8	13.1	13.1	38.9	38.9	94.3	85.1
25.5-28.4	203.0	182.6	52.4	46.8	15.8	14.2	34.0	29.0	100.8	92.4
28.5-31.4	83.5	75.2	21.0	21.0	0	0	42.0	37.8	20.5	16.4
31.5-34.4	73.2	70.8	23.9	23.9	0	0	0	0	49.3	46.9
34.5+	321.2	283.4	110.7	101.9	0	0	58.3	52.5	152.2	129.0
Slabs	25.0	23.6	21.3	20.2	2.0	2.0	1.8	1.4	0	0
Total	3,659.0	3,473.0	776.5	746.3	624.8	598.4	1,006.9	960.3	1,250.6	1,167.6
50+ percent sound:										
3.0- 4.4	248.5	240.2	108.6	104.2	71.3	69.1	43.7	43.0	24.8	23.8
4.5- 7.4	563.2	537.6	125.0	116.8	103.5	99.6	175.6	167.8	159.2	153.4
7.5-10.4	582.4	542.4	71.3	67.0	148.1	140.0	169.8	159.8	193.0	175.6
10.5-13.4	570.0	515.6	73.6	69.0	107.8	95.6	189.8	173.3	198.8	177.8
13.5-16.4	591.2	524.4	104.8	100.1	90.9	76.9	165.0	148.0	230.5	199.3
16.5-19.4	354.0	294.3	76.6	65.6	64.5	59.2	89.6	74.8	123.2	94.7
19.5-22.4	494.2	409.8	61.4	50.4	110.8	91.4	134.1	118.1	188.0	149.9
22.5-25.4	290.6	232.6	52.4	38.9	38.8	31.2	65.8	55.0	133.6	107.4
25.5-28.4	370.3	279.9	52.4	46.8	32.8	22.7	83.4	57.1	201.8	153.1
28.5-31.4	189.3	141.0	21.0	21.0	0	0	42.0	37.8	126.4	82.2
31.5-34.4	168.1	132.6	23.9	23.9	23.3	14.0	0	0	121.0	94.6
34.5+	469.4	372.2	110.7	101.9	0	0	87.8	73.2	271.0	197.2
Slabs	41.8	33.6	30.4	25.4	4.8	3.9	6.5	4.2	0	0
Total	4,933.0	4,256.2	912.1	831.0	796.6	703.6	1,253.1	1,112.1	1,971.3	1,609.0
30+ percent sound:										
3.0- 4.4	250.6	241.1	110.4	105.0	71.6	69.2	43.9	43.1	24.8	23.8
4.5- 7.4	575.0	541.8	130.3	118.6	106.8	100.9	177.5	168.6	160.4	153.7
7.5-10.4	614.7	554.0	75.0	68.2	154.7	142.2	177.0	162.2	208.0	181.4
10.5-13.4	598.0	525.4	76.4	69.8	107.8	95.6	203.0	178.2	211.0	181.8
13.5-16.4	640.8	541.8	104.8	100.1	111.8	84.2	183.2	154.0	240.9	203.4
16.5-19.4	389.4	306.4	76.6	65.6	71.8	61.4	97.0	77.0	144.0	102.4
19.5-22.4	607.0	449.6	61.4	50.4	131.2	98.5	176.7	134.1	237.7	166.7
22.5-25.4	370.6	259.2	52.4	38.9	52.3	35.2	118.8	72.3	147.0	112.8
25.5-28.4	437.6	306.8	52.4	46.8	48.6	29.0	119.6	71.6	217.2	159.4
28.5-31.4	272.8	170.3	42.0	27.3	0	0	42.0	37.8	188.8	105.2
31.5-34.4	222.0	154.1	23.9	23.9	23.3	14.0	0	0	174.8	116.2
34.5+	469.4	372.2	110.7	101.9	0	0	87.8	73.2	271.0	197.2
Slabs	42.6	33.9	31.4	25.7	4.8	3.9	6.5	4.2	0	0
Total	5,490.5	4,456.6	947.7	842.2	884.7	734.1	1,433.0	1,176.3	2,225.6	1,704.0
10+ percent sound:										
3.0- 4.4	253.0	241.4	111.9	105.2	71.7	69.2	44.4	43.2	24.8	23.8
4.5- 7.4	582.4	542.8	132.8	119.0	108.2	101.2	181.0	169.0	160.4	153.7
7.5-10.4	633.6	557.0	83.6	69.4	156.6	142.6	181.2	162.8	212.2	182.2
10.5-13.4	633.2	530.3	83.6	70.8	114.0	96.2	210.8	179.8	224.8	183.4
13.5-16.4	695.4	550.6	115.2	101.6	120.9	85.0	192.4	155.8	267.0	208.2
16.5-19.4	432.6	313.4	83.2	66.9	79.2	62.8	103.6	78.4	166.6	105.4
19.5-22.4	629.5	454.2	61.4	50.4	131.2	98.5	176.7	134.1	260.2	171.2
22.5-25.4	396.3	261.8	52.4	38.9	52.3	35.2	132.3	73.6	159.4	114.0
25.5-28.4	508.2	321.0	68.1	50.0	48.6	29.0	137.8	75.2	253.7	166.7
28.5-31.4	272.8	170.3	42.0	27.3	0	0	42.0	37.8	188.8	105.2
31.5-34.4	275.3	164.8	23.9	23.9	23.3	14.0	0	0	228.2	126.9
34.5+	607.2	396.8	110.7	101.9	0	0	125.2	80.6	371.4	214.4
Slabs	54.0	36.1	33.0	26.0	4.8	3.9	16.1	6.2	0	0
Total	5,973.5	4,540.5	1,001.8	851.3	910.8	737.6	1,543.5	1,196.5	2,517.5	1,755.1

1/ Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

Table 6.--*Average number of pieces per acre of usable prelogging residue by diameter and length classes, Pansy Creek balloon logging sale*[1/]

Diameter class (inches)	All classes	Length class (feet)			
		4.0-7.9	8.0-13.9	14.0-20.9	21.0+
3.0- 4.4	70.5	39.5	20.0	7.5	4.0
4.5- 7.4	51.0	12.0	17.0	9.0	13.5
7.5-10.4	49.0	17.5	5.5	9.5	16.0
10.5-13.4	28.5	6.0	3.0	7.0	12.5
13.5-16.4	12.5	1.5	1.0	3.5	7.0
16.5-19.4	9.5	2.5	1.0	3.5	3.0
19.5-22.4	9.5	1.0	1.5	2.5	5.0
22.5-25.4	7.5	1.5	1.5	1.5	3.5
25.5-28.4	3.0	0	1.0	1.0	1.5
28.5-31.4	5.5	1.5	1.5	1.0	1.0
31.5-34.4	1.0	0	.5	0	1.0
34.5+	8.5	1.0	0	2.5	5.0
Slabs	3.0	2.5	.5	0	0
Total	259.0	86.5	54.0	48.5	73.0

[1/] Includes all dead and down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, at least 10 percent sound, and yardable.

Table 7.--*Average number of pieces per acre of usable logging residue by soundness and by diameter and length classes, Piney Creek ball-on logging sale*[1/]

Percent soundness and diameter class (inches)	All classes	Length class (feet)			
		4.0-7.9	8.0-13.9	14.0-20.9	21.0+
75+ percent sound:					
3.0- 4.4	450.0	297.5	102.0	36.5	14.0
4.5- 7.4	244.0	110.5	53.0	50.5	30.5
7.5-10.4	98.0	29.5	30.0	22.0	16.0
10.5-13.4	47.0	15.5	11.5	12.5	8.0
13.5-16.4	31.0	14.0	5.0	6.5	5.5
16.5-19.4	12.5	5.5	3.5	2.5	1.5
19.5-22.4	10.0	2.5	3.0	2.5	1.5
22.5-25.4	4.0	2.0	.5	.5	1.0
25.5-28.4	4.5	2.5	.5	.5	1.0
28.5-31.4	1.5	1.0	0	.5	0
31.5-34.4	1.0	1.0	0	0	.5
34.5+	3.0	2.5	0	.5	.5
Slabs	16.5	15.5	.5	.5	0
Total	923.0	499.5	209.5	135.5	80.0
50+ percent sound:					
3.0- 4.4	473.0	314.0	107.0	37.5	15.0
4.5- 7.4	264.5	123.0	54.5	54.5	32.5
7.5-10.4	108.0	33.0	33.0	24.0	18.0
10.5-13.4	54.5	17.0	13.5	13.5	10.0
13.5-16.4	38.5	15.5	7.5	8.0	8.0
16.5-19.4	17.0	7.5	4.0	3.0	2.5
19.5-22.4	16.0	4.5	4.5	3.5	3.0
22.5-25.4	7.5	3.5	1.5	1.0	1.5
25.5-28.4	6.0	2.5	1.0	1.0	2.0
28.5-31.4	2.5	1.0	0	.5	1.0
31.5-34.4	2.0	1.0	.5	0	1.0
34.5+	4.0	2.5	0	.5	1.0
Slabs	20.0	18.0	1.5	1.0	0
Total	1,013.5	543.0	228.5	148.0	95.5
30+ percent sound:					
3.0- 4.4	478.5	318.5	107.5	37.5	15.0
4.5- 7.4	273.0	129.0	56.5	55.0	32.5
7.5-10.4	113.5	34.0	34.5	25.5	19.5
10.5-13.4	57.0	18.0	13.5	15.5	10.5
13.5-16.4	41.5	15.5	9.0	9.0	8.0
16.5-19.4	18.5	7.5	4.0	3.0	3.5
19.5-22.4	18.5	4.5	5.5	4.5	4.0
22.5-25.4	9.0	3.5	1.5	2.0	2.0
25.5-28.4	7.5	2.5	1.0	2.0	2.0
28.5-31.4	3.5	1.5	0	.5	1.5
31.5-34.4	2.5	1.0	.5	0	1.0
34.5+	4.0	2.5	0	.5	1.0
Slabs	21.5	19.0	1.5	1.0	0
Total	1,048.5	557.0	235.0	156.0	100.5
10+ percent sound:					
3.0- 4.4	484.5	323.5	107.5	38.5	15.0
4.5- 7.4	277.0	131.0	57.0	56.0	32.5
7.5-10.4	118.5	38.5	35.0	26.0	19.5
10.5-13.4	60.5	19.5	14.0	16.0	11.5
13.5-16.4	45.0	17.0	10.0	10.0	9.0
16.5-19.4	20.5	8.5	4.5	3.5	4.0
19.5-22.4	19.0	4.5	5.5	4.5	4.5
22.5-25.4	9.5	3.5	1.5	2.5	2.0
25.5-28.4	8.5	3.0	1.0	2.0	2.5
28.5-31.4	3.5	1.5	0	.5	1.5
31.5-34.4	2.5	1.0	.5	0	1.5
34.5+	4.5	2.5	0	.5	2.0
Slabs	23.5	21.0	1.5	1.0	0
Total	1,077.0	575.0	238.0	161.0	105.5

[1/] Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

Table 8.--*Average gross and net volumes of usable logging residue by soundness and material handling class, Pansy Creek balloon logging sale*[1/]

Percent soundness and material handling class	Gross volume	Net volume	Soundness	Proportion of total
	-Cubic feet per acre-		*- - - - Percent - - - -*	
75+ percent sound:				
Felled and bucked	1,376.1	1,352.0	98.2	37.6
Felled and broken	1,237.4	1,196.4	96.7	33.8
Down and bucked	419.5	370.6	88.3	11.5
Down and broken	625.8	553.7	88.5	17.1
Total	3,658.8	3,472.7	94.9	100.0
50+ percent sound:				
Felled and bucked	1,500.6	1,431.3	95.4	30.4
Felled and broken	1,390.8	1,290.6	92.8	28.2
Down and bucked	832.0	629.6	75.7	16.9
Down and broken	1,209.6	904.8	74.8	24.5
Total	4,933.0	4,256.3	86.3	100.0
30+ percent sound:				
Felled and bucked	1,532.8	1,443.4	94.2	27.9
Felled and broken	1,434.4	1,307.6	91.2	26.1
Down and bucked	979.4	678.2	69.2	17.8
Down and broken	1,544.4	1,027.3	66.5	28.1
Total	5,491.0	4,456.5	81.2	[2/]99.9
10+ percent sound:				
Felled and bucked	1,610.5	1,457.4	90.5	27.0
Felled and broken	1,503.6	1,315.7	87.5	25.2
Down and bucked	1,123.6	705.8	62.8	18.8
Down and broken	1,736.0	1,061.6	61.2	29.1
Total	5,973.7	4,540.5	76.0	[2/]100.1

[1/] Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

[2/] Total does not equal 100 because of rounding.

bucked from larger pieces (i.e., felled and bucked plus down and bucked classes, (table 8)). A portion of this volume might have been salvaged with an alternative bucking procedure. Such a procedure would minimize the amount of tree bole residue left on the area by limiting long butting and bucking out of defective segments and broken log ends. This material would then be yarded with the merchantable portion of the logs.

CONCLUDING REMARKS

Information contained in this report was obtained from a clearcut, balloon logged area. Comparable information from areas logged by helicopter and skyline systems is nearing completion. Results from these studies will be reported in separate papers.

Since the present investigation is only a case study, results are not necessarily indicative of other balloon logging operations. Still, the information presented can be used by forest managers, who are continually confronted with the problems of residue production, its reduction, and evaluation of the characteristics, volumes, and potential uses of the residues generated. It provides some indication of the fuel loading that can be expected from similar harvesting operations. It further provides a basis for evaluating the effects of changes in utilization either from changes in the market or in contractual requirements such as required yarding of unutilized material (YUM).

Results of this study strongly suggest that a substantial volume of usable residues can be salvaged by modifying bucking practices. This is particularly feasible where a defective but usable portion of the bole is left attached and removed with the more merchantable portion of the stem.

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METRIC CONVERSIONS

1 hectare = 2.471 05 acres

1 cubic foot per acre = 0.069 972 5 cubic meter/hectare

1 inch = 2.54 centimeters

1 foot = 0.304 8 meter

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

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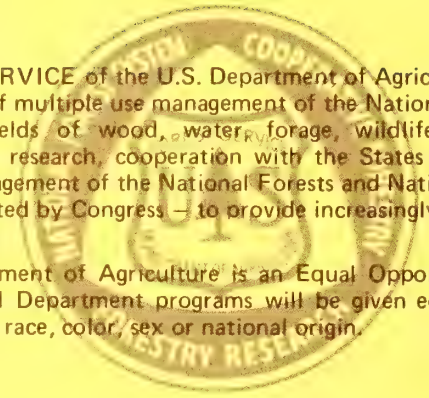

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-273 July 1976

LOGGING TO SAVE PONDEROSA PINE REGENERATION: A CASE STUDY

by

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ABSTRACT

Marking understory crop trees before logging a 24,000-board feet-per-acre stand of mature ponderosa pine resulted in preserving 180 crop trees per acre over three-fourths of the area. Falling caused more damage to prospective crop trees than skidding. Three-stage logging on flat ground did not seem necessary in this test. A front-end grapple did less damage to residual crop trees in piling slash than a conventional crawler tractor with slash blade, but the tractor piled more of the smaller material. Following the procedure demonstrated in this case study would cost a little less than clear-cutting and planting, using present-day expenses in central Oregon.

KEYWORDS: Regeneration methods -)economic evaluation, ponderosa pine, *Pinus ponderosa*, logging (-regeneration, understory layer.

Ponderosa pine (*Pinus ponderosa*) harvesting in the Pacific Northwest may be broadly grouped into four systems--clearcutting, seed tree, selection, and shelterwood. Under the latter three, an attempt is made to preserve younger trees in the stand. Clearcutting, on the other hand, means that the understory trees, if present, will be destroyed and the area replanted. Where young trees are badly diseased, clearcutting is usually the only alternative, although occasionally seed tree or shelterwood may be used if the overstory is quickly removed after the regeneration is established.

In a healthy stand where overstory volume is light, forest managers generally try to harvest the merchantable trees and save the understory. However, where stands contain a heavy overstory volume (20,000 board feet or more per acre), managers often differ in their prescription for the area. One manager may choose to clearcut, while another prefers to carefully remove the overstory and save a portion of the understory. Such choices apparently stem from good and bad experiences in logging. Where heavy volumes occur in central Oregon, some attempts to save an adequate number of understory trees have been discouraging.

There are several million acres of ponderosa pine land in the Pacific Northwest where the incentive to save the understory is great, where preserving trees from 1 to 8 inches in diameter and 6 to 30 feet in height would be equivalent to 10- to 30-year-old planted trees. If enough trees could be saved to adequately stock the area, the job of site preparation and planting could be eliminated; and some saving in maturity time is possible. Furthermore, the area would be stocked with well-established trees highly adapted to the site through many generations of natural selection. Also, the land is kept green, and the objectionable denuded appearance that results from clearcutting and planting is avoided.

The western forest manager has been concerned for decades about saving residual understory trees. Considerable success in reducing damage to residual trees was achieved from 1950 to 1960 (Hallin 1959, Cosens 1952). Smaller, more maneuverable yarding equipment and a detailed logging plan were emphasized. In addition, stage cutting and skid trail, road, and land location were recognized as worthwhile steps for the orderly removal of timber.

A lot of eyeball and some detailed (Foiles 1962) appraisals of residual stand condition after logging have been based on damage or reduced stocking rather than how many crop trees per acre were left. In logging seed trees from a regenerated area, McDonald (1969) set up a stocking standard and then designed a harvest procedure to keep this desired stocking. Rather than appraise damage in the study reported here,[1/] we chose to set a partial stocking standard by marking leave trees and instructing the logger to avoid the marked trees; i.e., damage was not studied but stocking of usable trees was.

This note presents results of logging a 40-acre[2/] stand of mature ponderosa pine where understory saplings and poles were marked to save. All phases of logging and slash disposal were monitored to identify stocking changes associated with each operation.

[1/] A cooperative effort between the Deschutes National Forest and the Pacific Northwest Forest and Range Experiment Station.

[2/] One acre equals 0.4 of a hectare.

Experience has shown that good communication between a timber purchaser and the Forest Service is essential for a good job of logging. In view of this, a prelogging conference was held in the woods with representatives of the purchaser, Gilchrist Timber Co. of Gilchrist, Oregon, Deschutes National Forest Timber sale administrators, and the Pacific Northwest Forest and Range Experiment Station. Objectives of the study were jointly discussed by the sale administrator and the timber company before logging began, and instructions given to fallers and skidders by company supervisors. Communication between company supervisors, workers, and sale administrators was maintained daily throughout the logging operation.

THE STUDY

Objective

Keep in mind that this was an exploratory trial in preserving understory trees by the "mark leave tree method." In addition, we wished to compare the option of two- versus three-stage logging and to identify the logging process most damaging to marked trees. Since fuel buildup in our public lands is of prime concern in preventing catastrophic fires, we also wished to compare two methods of heavy fuel disposal.

The study was done on the Pringle Falls Experimental Forest, 35 miles southwest of Bend, Oregon. Logging was done during the spring of 1973.

Stand Characteristics

Before logging in 1973, the two-storied stand contained evenly distributed, mature and overmature ponderosa and lodgepole pine (*Pinus contorta*) in the overstory, with a heavily stocked, suppressed understory of the same two species (fig. 1). Gross standing volume of

Figure 1.--Before logging ponderosa pine with understory of saplings. The old skid trail in the foreground was established during a light sanitation cut early in the 1950's. Such trails were utilized in completely removing the overstory in this study.

merchantable trees was 24,000 board feet per acre. Lodgepole pine constituted only about 1 percent of total volume. About 4,000 board feet per acre had been removed in the late 1950's and 1960's. The average merchantable lodgepole tree was 14 inches[3/] in diameter and contained 2.3 16-foot[4/] logs. The average ponderosa pine tree was much larger, being 28 inches in diameter and 4.3 logs long.

Just before the 1973 harvest, understory density averaged about 5,000 stems per acre. A few lightly stocked areas of understory could be found where overstory density was high. Understory trees were mostly sapling-sized trees 1-5 inches in diameter and 4 to 20 feet in height. Although this suppressed ponderosa pine understory ranged in age from 50 to 80 years, a previous study showed that such trees would respond remarkably well to release (Barrett 1973). Small lodgepole pine poles, with poor crowns and infected with dwarf mistletoe and western gall rust, were scattered throughout the stand.

Antelope bitterbrush (*Purshia tridentata*) was the predominant ground vegetation, although snowbrush ceanothus (*Ceanothus velutinus*) and pine manzanita (*Arctostaphylos parryana* var. *pinetorum*) were present. This brush did not hinder the logging.

Topography was predominantly flat, with a gentle slope on one side.

Methods

Before logging, on an average, 74 understory sapling-sized leave trees per acre (24- x 24-foot average spacing) were marked with paint as crop trees to be avoided by the logger. Trees were marked at a spacing that seemed reasonable at the time for maneuvering of skidding equipment between trees. Observation of other logging has shown that trees tend to be left in thickets and that single trees in openings are destroyed. We reasoned that, by marking the leave trees, we would end up with a systematic pattern throughout the stand. A final stocking of 180 trees per acre (15.5-foot spacing) was our goal. Thirty-eight 0.4-acre circular sample plots were spaced mechanically on a 200-foot grid over the 40 acres. Plot centers were permanently located with a steel rod driven into the ground. Location of all understory crop trees and marked overstory harvest trees on each plot was plotted with a transit equiped with stadia. This enabled us to find and observe each marked leave tree after each logging and slash disposal operation.

All overstory trees to be harvested were marked with paint before the sale. Trees on half of the area were felled and skidded in two stages and on the other half, in three stages. Overstory trees to be removed in the first stage were marked with blue paint, and these trees were felled towards and away from the landing, thus minimizing the need for turning logs when skidding. In the first stage, trees that would do the greatest damage were cut, such as heavy leaners and those with large limbs and heavy crowns. Trees in the second stage were marked with white paint and in the third, with green paint. Approximately one-half and one-third of the volume was removed in each stage of two- and three- stage logging.

[3/] One inch equals 2.5 centimeters.

[4/] One foot equals 0.3 of a meter.

After logging and before slash disposal, additional understory trees were marked, bringing the average number of residual trees per acre up to 106 (20- x 20-foot spacing). This gave us a new, more realistic spacing of trees on which to judge crop tree loss resulting from slash disposal. Logging slash on half of the area was piled with a conventional, crawler-type tractor and brush blade and on the other half, with a grapple-type, front-end loader. The east half was logged in three stages; the west half, in two stages. Slash on the north half was piled with a tractor and on the south half, with a grapple. Treatment areas were chosen by flipping a coin. Log landings, by chance, fell outside all 0.4-acre plots.

After slash burning, a stocking survey on a 1-chain[5/] grid was made. A grid point was considered stocked if a tree was present that was at least 12 inches high and of good thrift. Although there were very few trees as small as 12 inches, we selected this minimum standard because it would be equivalent to a 3-0 planted tree. A stocking standard of 180 trees per acre was established as a possible goal for the area. If a tree was found in a circle representing the area occupied by one tree in a 180-tree-per-acre stand, the grid point was considered stocked for the density goal. This density standard was used because on the Deschutes National Forest about 180 trees per acre are left in many precommercial thinnings.

Since treatments were not replicated, statistical analysis could not be done. Further study will be replicated over a range of geographical conditions to make results broadly applicable.

Logging

Fallers were instructed to fall first-stage trees either toward or away from landings, but they selected direction of tree fall in the second and third stages. No skid trails were marked and tractor operators were instructed to use their skill in avoiding marked leave trees. Skidding was done with a crawler-type tractor and rear-mounted hydraulic grapple tongs. Since an arch and chokers were not involved, tractor maneuverability was good.

The area was bounded on two sides by National Forest system roads and divided by a spur road. Logs were loaded from landings at the edge of roads.

Damage to marked leave trees was monitored after each of the following operations: first-stage falling, first-stage skidding, second-stage falling, second-stage skidding, third-stage falling, third-stage skidding, slash piling, and slash burning.

[5/] One chain equals 20.1 meters.

RESULTS

Logging

Almost 20 percent of the understory trees originally marked were lost in logging when data from all 30 plots were averaged (fig. 2). Of this loss, 66 percent was due to falling and 34 percent, to skidding. Most falling damage to residual saplings and pole-sized trees consisted of top break. Where only the current year's height growth was broken, the tree was tallied as a usable crop tree. A break lower on the bole was tallied as a tree loss.

Figure 2.--After logging the stand shown in figure 1. Trees with black dots are leave trees marked as part of the 74 trees per acre originally marked. Badly bent tree would be considered a loss.

When the data are separated into plots where two-stage logging (21 plots) and three-stage logging (17 plots) were applied, averages indicate a slight advantage to three-stage logging (table 1). Skidding losses for two-stage logging averaged slightly more than 1 1/2 times that for three stages. Greatest losses from two- and three-stage falling occurred during the second stage. Heaviest losses from skidding (figs. 3, 4, and 5) in three-stage logging occurred in the first stage and gradually diminished through the third stage. In two-stage logging, heaviest skidding losses also occurred in the first stage.

An average of 75 pieces per acre was skidded from the area. Pieces ranged from 10 to 32 feet long.

Table 1--*Percent of the original number of marked trees lost in falling and skidding in two- and three-stage logging*

System	First stage		Second stage		Third stage		Total all stages		Fall + skid
	Falling	Skidding	Falling	Skidding	Falling	Skidding	Falling	Skidding	
	Percent								
Two-stage (68)[1/]	6.1	6.3	6.9	1.6	--	--	13.0	7.9	20.9
Three-stage (79)[1/]	4.3	2.8	6.1	1.5	2.8	0.35	13.2	4.7	17.9

[1/] Average number of understory leave trees per acre initially marked in stands logged in 2 and 3 stages.

Figure 3.--Thirty-two-foot log being carefully removed from an area of marked leave trees.

Figure 4.--Log bunching areas were usually located along main skid trails.

Figure 5.--Even though this appears to be a large turn of logs to manipulate between trees, skidding caused only about one-third of the logging damage.

Slash Disposal

As mentioned, additional crop trees were marked after logging to provide a reasonable tree density for comparing two methods of piling slash.

Over the total area, only about 6 percent of 106 crop trees per acre were lost to piling and only 1 percent to burning. Greater damage was done by the crawler-type tractor with a conventional brush blade (figs. 6 and 7) than by the front-end grapple. About a 9-percent loss was observed on cat-treated plots compared with 3 percent for the grapple (figs. 8, 9, and 10). Both machines were required to pile approximately 70 percent of material down to 4 inches in diameter and 6 feet long, plus pieces 10 feet or more in length regardless of diameter. The grapple piled only this much because smaller material fell through the forks of the front-end grapple (fig. 11). The tractor, on the other hand, piled much more smaller material simply because it was in the path of the brush blade.

Slash piles were placed in nonstocked holes in the stand that were 30-35 feet in diameter. If there was room, a fireline was cleared around the pile. Piles were approximately 15 feet in diameter and 10 feet high. About 8 percent of the total land area was used for the slash pile and for tractor-maneuvering room around the pile.

A survey after slash burning showed that if our stocking goal of 180 trees per acre was met, the area would be 75-percent stocked with trees averaging about 3 inches in diameter and 12 feet high. The 11 log landings included in the stocking survey covered about 1.3 acres, or 3 percent of the logged area.

Figure 6.--Slash tractor working heavy fuels out so material may be burned.

Figure 7.--Only lighter fuels remain after pass with slash tractor.

Figure 8.--Front-end grapple picking a chunk of "hot" fuel from a reproduction thicket.

Figure 9.--Large pieces may be transported to the pile at a height that will not damage sapling reproduction.

Figure 10.--Slash this long is difficult to move to the slash pile and should be bucked before being picked up.

Figure 11.--Small pieces of slash fall through the forks of the front-end grapple.

DISCUSSION

Tree Stocking

In this study, we were able to preserve 180 trees on 75 percent of the area. There are nonstocked areas in the stand where slash was piled, skid trails converged, and logs were loaded. The remaining sapling stand now needs to be thinned and the thinning slash crushed (Dell and Ward 1969). The thinner will leave the necessary number of trees in addition to those marked to bring tree density up to the desired level.

There is a question as to the necessity for planting about 15 trees per acre to fill in nonstocked holes where slash was piled and burned. Also, most managers agree that planting landings and major skid trails is not worth the effort, as they will be used again in the first commercial harvest.

Slash Disposal

Currently, some managers are reluctant to cut a 20,000-board foot-per-acre stand in two or three stages in one sale because they feel the large amounts of slash cannot be piled without losing a large number of crop trees. A stand of 24,000 board feet is sometimes cut in three different sales of 8,000 each, cleaning up the logging slash each time.

Marking separate sales may not be necessary. In this sale, all slash from 24,000 board feet was piled and burned without losing more than about 6 percent of the marked crop trees. Furthermore, enough additional trees were spared that a total stocking of at least 180 trees per acre were left over three-fourths of the area. This and other experience on the Deschutes National Forest also suggest that the slash from 24,000 board feet can be disposed of for considerably less money when cut in one sale than in three separate sales.

Stage Logging

Three-stage logging did not appear to be worth the effort in this trial, although a small difference in favor of three stages over two stages was found.

Since trees marked in the first stage were those likely to do the most damage, it is difficult to explain why second-stage falling damage was greater than the first. We had intended to have second-stage trees felled into beds created by trees felled in the first stage. Fallers, however, often resisted this because it meant working in slash created in the first stage. Also, there is a limit to how far a tree may be pulled. Some sale administrators believe that the skill involved in the first-stage tree selection and falling determines how much damage will be done in succeeding stages.

Method Improvement

Observation of tractors working their way through marked trees indicates that more than 70 trees per acre could be marked. This in

turn would restrict skidding somewhat but might improve stocking. Obviously we could mark too many trees and set up an unreasonable situation for the logger. It doesn't appear necessary to mark as many trees as the stocking goal. For example, if we mark 150 trees and achieve 75 percent of a goal of 180 crop trees per acre, we could require the thinner to leave enough additional trees without spacing some trees closer than 10 feet.

Systematic location of skid trails would probably promote a more orderly removal of logs. The trails could be located before logging when there is adequate time to consider timber and landing location and topography. This practice would reduce the number of skidder decisions and thus increase efficiency and skill in manipulating logs into the marked trail.

Losses in falling appeared to set the stage for skidding patterns in some instances. For example, when the tractor operator found a damaged marked tree, he sometimes used that as an avenue in the stand through which to proceed. If this happens often, it could lead to poor stocking distribution. The logger should avoid these damaged marked trees and thus preserve surrounding trees.

Great care should be used in marking trees to be cut in the first stage. Possibly less volume should be cut in the first stage. Skidding patterns could be established for orderly removal of the next stage.

The front-end grapple shows some promise in piling where an understory is to be saved. However, some improvements in the design of the grapple are necessary to keep large, short pieces from dropping through the forks.

As a further cost reduction in slash treatment, the option of broadcast prescribed burning without piling needs to be explored.

Economic Considerations

Forest managers usually consider two alternatives for regenerating a mature ponderosa pine stand with a heavy volume and a sapling understory in central Oregon. One is to clearcut, prepare the site, and plant. The other is to save enough selected trees in the understory by careful logging to adequately stock the site. Elements of expense in the save-the-understory method that do not occur in clearcutting are: marking crop trees, additional cost of falling and skidding care, thinning, and crushing thinning slash. Following the procedure demonstrated here, saving the understory would cost a little less than planting, using present-day expenses in central Oregon.

A direct result of saving the understory is that commercial harvests from the next crop of timber will be realized approximately 15 years sooner than if the site was regenerated by planting after a clearcut. Although there appear to be obvious advantages to harvesting the next crop of timber 15 years sooner, the additional wood does not account for much of an economic gain when discounted to present value at currently acceptable interest rates. The roughly 12-percent growth increase may, however, increase the rate of old-growth harvest through the allowable

cut effect (Schweitzer et al. 1972). A much greater economic impact can be realized by reducing regeneration costs, since these costs represent an immediate outlay of capital that is not discounted.

Using the understory and thus keeping the site "green" is a benefit that is difficult to evaluate in monetary terms, yet it is important to a significant portion of our society. Also difficult to measure is the value received from regenerating a site with trees that may represent thousands of years of natural selection. Perhaps the most important point to consider is the "bird in hand" concept. There is no absolute guarantee of regenerating a stand following clearcutting; but with the save-the-understory method, the trees are already there.

Application

In applying these results, it should be kept in mind that this is a case study carried out on an Experimental Forest, with a given stand condition, and a cooperative timber purchaser. However, other major timber purchasers on the Deschutes National Forest are demonstrating their ability to do quality work in overstory removal logging. Some caution should be taken in applying these results to other areas and purchasers. Hopefully, forest managers will be encouraged to try overstory removal logging, rather than to clearcut, where overstory volume is heavy as well as where it is light.

What's Next?

This method of marking the understory needs testing in areas large enough so that marking versus not marking can be compared and a statistically sound inference made. Although this trial did not lend itself to statistical tests, it does suggest what aspects should be incorporated into a series of trials throughout central Oregon. We propose to locate eight 40-acre tracts that are uniform enough so that half of the tract can be marked and half left unmarked. These trials would be carried out over several years so that variation in weather, purchaser, terrain, and stand characteristics would be sampled. In addition, costs and benefits of three alternatives--marking understory, not marking, and clearcutting and planting--could be fully studied. Persons interested in cooperating in such trials on lands under their management should contact the U.S. Forest Service Silviculture Laboratory, 1027 N.W. Trenton Ave., Bend, Oregon 97701.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-274 August 1976

RELATIONSHIP OF SHOOT-ROOT RATIO TO SURVIVAL AND GROWTH OF OUTPLANTED DOUGLAS-FIR AND PONDEROSA PINE SEEDLINGS

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ABSTRACT

Two-year-old Douglas-fir and ponderosa pine seedlings with three top heights, and with either large or small roots, were planted in a burned-over area in north-central Washington to evaluate the relationship of shoot-root ratio to first-year survival and shoot growth. Survival of fir seedlings with large roots was 22 to 26 percent higher than survival of seedlings with small roots, and pine survival was increased 5 to 15 percent. Shoot growth (increase in shoot mass) of large-rooted fir and pine seedlings was as much as 2.1 and 4.8 times, respectively, that of small-rooted seedlings. Height growth of both fir and pine seedlings with large roots was 1.2 to 1.7 times that of seedlings with small roots.

KEYWORDS: Root development (-shoot growth, seedling survival, Douglas-fir, *Pseudotsuga menziesii*, ponderosa pine, *Pinus ponderosa*.

Shoot-root ratio is an important factor in survival of planted conifer seedlings, because shoot and root sizes directly affect water loss and uptake and hence the internal water stress of seedlings after outplanting. Hermann (1964), in a test with Coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), found that survival of seedlings with small roots was significantly lower than survival of seedlings with large roots, regardless of size of top. Also, Carlson (1972) found that the survival of jack pine (*Pinus banksiana* Lamb.) seedlings with low shoot-root ratios was higher than survival of seedlings with relatively high ratios. Edgren,[1/] discussing factors in regeneration success of coastal Douglas-fir, regards a top-to-root ratio of 2:1 as acceptable for dry sites and possibly 4:1 for wet sites. However, information is limited concerning the relationship of shoot-root ratios to survival in most species and in varieties of a given species. This report describes the relationship of shoot-root ratio and height of top to survival and growth of Rocky Mountain Douglas-fir (var. *glauca*) and ponderosa pine (*Pinus ponderosa* Laws.) seedlings on a dry site.

METHODS

Seedlings were planted on two sites differing somewhat in dryness, in the Brennegan Creek watershed, a tributary of the Entiat River in north-central Washington. Elevation ranged from 900 to 1150 m (3,000 to 3,800 ft). Exposure varied from east to southwest and slope, from 20 to 40 percent. Average annual precipitation at 900 m is 55.9 cm (22 in) per year, and mean annual temperature is 6.8 °C (44.3 °F). Summers normally are hot and dry, with only about 13 percent of the precipitation occurring from June to September (fig. 1).

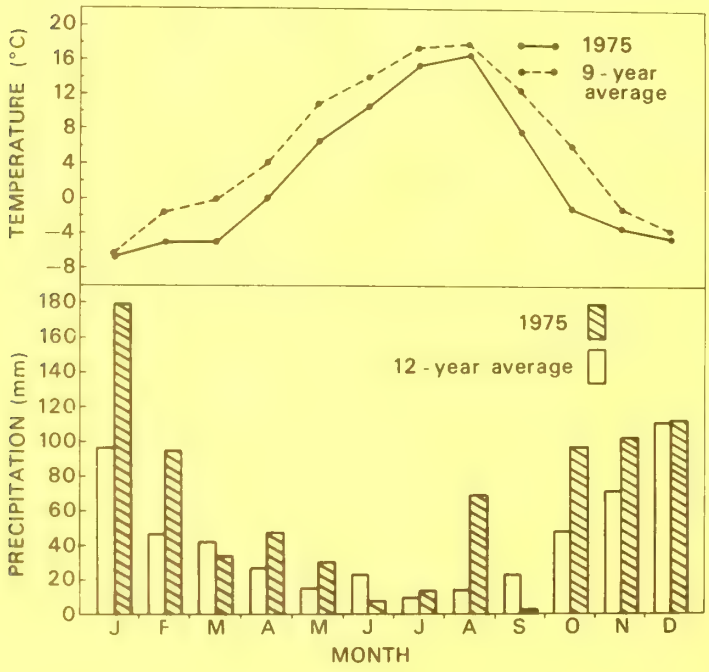

Figure 1.--Mean monthly precipitation and temperature at 880 meters (2,900 ft) in a watershed adjacent to the planted area show relatively high precipitation and low air temperature during 1975 compared with previous average values. The rainfall during August 1975 occurred during a 2-day period, thoroughly wetting the soil in the seedling root zone.

[1/] Edgren, J. 1975. Factors in regeneration success. Talk presented to U.S. Forest Service R-6 Silvicultural Workshops. [On file at U.S. For. Serv. For. Sci. Lab., Corvallis, Oreg.]

Soils are coarse and relatively deep, developing in coarse ash or pumice over granite bedrock and are classified as Stormy or Rampart sandy loams (Iritani 1965). Vegetation, after a severe forest fire in 1970, consisted mostly of artificially seeded orchardgrass (*Dactylis glomerata* L.) and scattered snowbrush ceanothus (*Ceanothus velutinus* Dougl.).

Two-year-old fir and pine seedlings, grown at nurseries at Wind River, Washington, and Bend, Oregon, from locally collected seed, were graded to obtain three arbitrarily selected top height classes. Height classes were:

Fir	Pine
7-11 cm (2.8-4.3 in)	7-11 cm (2.8-4.3 in)
14-18 cm (5.5-7.1 in)	12-16 cm (4.7-6.3 in)
21-25 cm (8.3-9.8 in)	17-21 cm (6.7-8.3 in)

Height of top was measured from the root collar to the tip of the terminal bud. Each height class was then graded to obtain seedlings with large and small root systems (fig. 2).

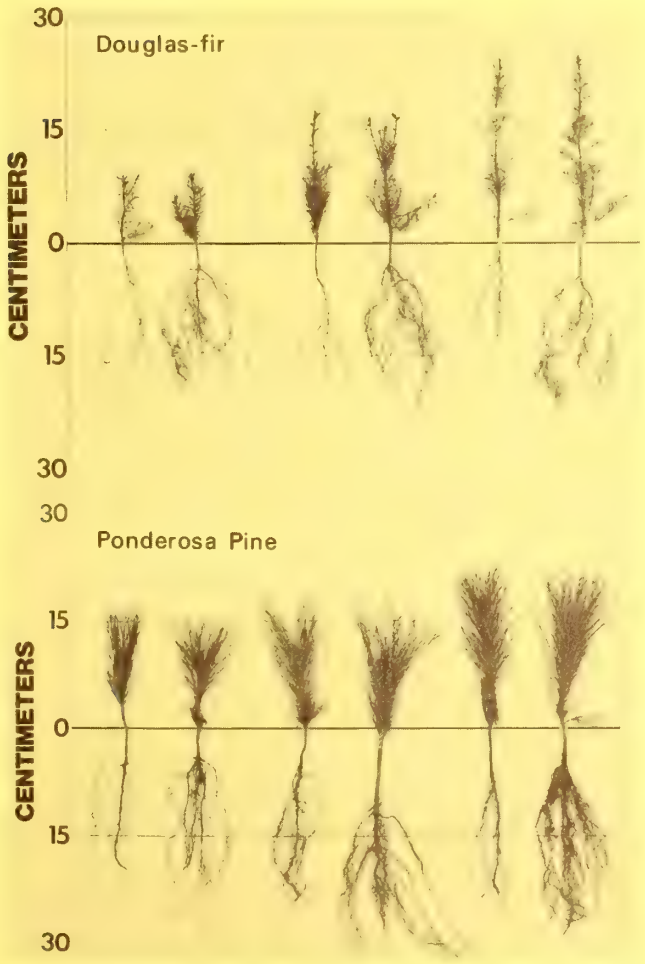

Figure 2.--Height and root classes of Douglas-fir and ponderosa pine seedlings used in the experiment. In each height class, seedlings on the right represent good root development; those on the left, poor development.

Twenty-five seedlings of each height and root class were used to characterize shoot-root ratios and stem diameters. Stem diameters were measured just below the root collar. Seedlings then were cut at the root collar, shaken to remove excess water, and the shoot and root weighed, ovendried, and reweighed to obtain fresh and dry weights. Top heights of the firs ranged from 7 to 25 cm (2.8 to 9.8 in), shoot-to-root ratio (ovendry basis) from 0.8 to 1.8, stem diameter from 2.9 to 6.1 mm (0.11 to 0.24 in), and seedling weight (ovendry basis) from 1.0 to 6.0 g (table 1). In the pines, top height ranged from 7 to 21 cm (2.8 to 8.3 in), shoot-to-root ratio from 1.5 to 2.7, stem diameter from 4.4 to 8.2 mm (0.17 to 0.32 in), and seedling dry weight from 2.9 to 10.5 g (table 2). In both species, shoot-root ratios on a fresh-weight basis were similar to those determined on a dry-weight basis.

Table 1--*Seedling characteristics, survival, and growth of 2-0 Douglas-fir seedlings*

Top size and root development	Shoot: root ratio[1/]		Stem diameter[1/]	Seedling weight[1/]		Survival	Height growth[2/]	Shoot growth[3/]
	Ovendry weight	Fresh weight		Dry	Fresh			
	Grams		Millimeters	Grams		Percent		
Small (7-11 cm):								
Large roots	0.8	0.7	3.8	1.9	7.1	82.5	27.2	80.5
Small roots	1.4	1.5	2.9	1.0	2.8	56.5	17.8	51.5
Medium (14-18 cm):								
Large roots	1.0	1.0	4.4	3.8	13.2	78.5	21.4	64.3
Small roots	1.5	1.6	3.5	1.6	5.3	56.5	17.8	49.6
Large (21-25 cm):								
Large roots	1.3	1.2	6.1	6.0	20.6	80.0	17.1	52.3
Small roots	1.8	1.8	4.3	3.1	9.7	58.4	11.2	25.5

1/ Each value is based on 25 measurements.

2/ $\frac{\text{final height-initial height}}{\text{initial height}} \times 100.$

3/ $\frac{\text{total weight of new shoot growth}}{\text{total weight of shoot-weight of new shoot growth}} \times 100.$

Table 2--*Seedling characteristics, survival, and growth of 2-0 ponderosa pine seedlings*

Top size and root development	Shoot: root ratio[1/]		Stem diameter[1/]	Seedling weight[1/]		Survival	Height growth[2/]	Shoot growth[3/]
	Ovendry weight	Fresh weight		Dry	Fresh			
	Grams		Millimeters	Grams		Percent		
Small (7-11 cm):								
Large roots	1.7	1.7	5.4	4.8	16.9	99.5	27.8	79.9
Small roots	2.1	2.3	4.4	2.9	10.3	94.0	19.1	16.8
Medium (12-16 cm):								
Large roots	1.5	1.4	8.2	10.5	34.7	98.5	20.7	35.4
Small roots	2.3	2.5	4.6	3.5	12.1	91.0	13.2	15.4
Large (17-21 cm):								
Large roots	2.1	2.0	7.3	9.1	30.9	97.5	18.1	39.8
Small roots	2.7	3.0	5.5	5.2	17.6	82.0	10.8	11.4

1/ Each value is based on 25 measurements.

2/ $\frac{\text{final height-initial height}}{\text{initial height}} \times 100.$

3/ $\frac{\text{total weight of new shoot growth}}{\text{total weight of shoot-weight of new shoot growth}} \times 100.$

In mid-May, 600 seedlings of each species were planted on each of the two sites, a total of 1,200 seedlings of each species. Seedlings were planted in a randomized block design with split plots (paired rows) within blocks. Blocks were replicated four times per species at each site, with 25 seedlings of each top and root class per replication. Each pair of rows consisted of a particular top size, with one row containing seedlings with good roots and the adjacent row, seedlings with poor roots. Planting spots were scalped free of vegetation, and the seedlings were hand planted with a hoedag. Soil moisture tension measured just before planting was 0.1 to 0.2 bar.

After planting, heights of seedlings were measured from ground surface to the tip of the terminal bud. A survival count was made in mid-October, 5 months after planting, and heights were remeasured. Seedlings were classified as dead only if all needles were brown and dry. Seedlings from one block of each species were dug up for determination of the total amount, by weight, of new shoot growth.

RESULTS

Except for height growth of the firs, survival and height growth of the two species were similar for the two planting sites; consequently, data from the two sites are combined in tables 1 and 2. Significance of differences was determined by analysis of variance. Survival of fir seedlings for all height and root classes ranged from 56.5 to 82.5 percent, with no significant effect of top height on survival within root classes. Survival of pine was higher, ranging from 82 to 99.5 percent, with survival of small seedlings slightly but not significantly higher than that of medium and large seedlings. The most conclusive result was that in both fir and pine of all height classes, survival of seedlings with large roots was significantly higher (1-percent level) than survival of those with small roots. In fir, the increase in survival ranged from 21.6 to 26 percent, and in pine, 5.5 to 15.5 percent, with no significant differences between top sizes.

Height growth was similar in fir and pine, ranging from about 11 to 27 percent for all height classes. Percent height growth increased with decrease in top height in both fir and pine, except in the case of small and medium fir seedlings with small roots; but differences were not significant. In both fir and pine, height growth of seedlings with large roots was 1.2 to 1.7 times the height growth of seedlings with small roots (significant at 5-percent level); there were no significant differences between top sizes.

The total amount of new shoot growth was greater in fir seedlings than in pine, with an average for all height classes and root classes of 54 percent for fir, compared with 33 percent for pine. In both fir and pine, the greatest amount of shoot growth occurred in small seedlings with large roots, and the least in large seedlings with small roots. Although a definite trend was indicated, the effect of top height on shoot growth was not significant. Shoot growth of fir seedlings with large roots was 1.3 to 2.1 times that of seedlings with small roots. In pine, shoot growth of large-rooted seedlings was 2.3 to 4.8 times that of small-rooted seedlings. In both species, differences were significant at the 5-percent level.

DISCUSSION

The increased survival of seedlings with low shoot-root ratios over those with higher ratios emphasizes the desirability of planting seedlings with large root systems. Weather during 1975 was not typical--cooler and moister than most years (fig. 1)--which apparently accounts for the relatively high survival found in most classes of seedlings. During a preliminary test in 1974, a warm, dry year, survival of both fir and pine seedlings was considerably lower than during 1975. However, the increase in survival as a result of low shoot-root ratio, for both fir and pine, was similar for both years.

The higher survival of the pine seedlings than the fir and the smaller beneficial effect of low shoot-root ratio suggest that shoot-to-root balance is less important in the pine than in the fir, possibly because of the inherently greater drought resistance of ponderosa pine.

Survival was not significantly influenced by seedling height in the present test; however, some workers have reported a relationship between top size and survival. Hermann (1964) found that the survival of Douglas-fir seedlings with large tops (38.1-50.8 cm; 15-20 in) was significantly lower than survival of those with smaller tops; in our study, the largest fir seedlings used were considerably smaller, with a top size of 21-25 cm (8.3-9.8 in). Smith and Walters (1965), also working with Douglas-fir, found that in the 2 years after planting, mortality was greater in very short and very tall seedlings. We have observed, in greenhouse plantings of Douglas-fir seedlings, that the smallest seedlings often exhibit very small amounts of shoot growth, indicating low vigor. However, such seedlings usually were smaller than those we used. Another consideration is that, in some studies, survival probably was influenced by variation in shoot-root ratio as well as top size, whereas this factor was controlled in our study.

Our results indicate that, in the range of seedling heights tested, proper balance between shoot and root systems probably is more important than top height alone. For example, we found that large seedlings with large roots survived better than small and medium seedlings with small roots. However, it should be noted that large seedlings often lack large enough root systems for good shoot-root balance, whereas good balance is frequently found in smaller seedlings.

Low shoot-root ratios also were associated with greater height growth and particularly with a greater amount of new shoot growth, which reflects greater vigor and subsequent growth potential in these seedlings. Part of the increase in amount of new shoot growth of fir seedlings with large roots was a direct result of the greater number of lateral shoots and buds initially present in such seedlings compared to seedlings with small roots (fig. 2). Such differences were not apparent in the pine seedlings, which typically have few lateral buds.

Prompt root growth often is mentioned as a key factor in survival of newly planted seedlings. When we dug up our seedlings at the end of the first growing season, any new root growth typically consisted of short roots with no significant root extension beyond the original root mass. Consequently, during the first year, seedlings must rely entirely on soil moisture in the

immediate vicinity of the initial root system. Although we did not measure root growth, we did note that only seedlings with large initial root systems showed considerable amounts of new root growth, and seedlings with small roots produced very little or no new growth. Thus on dry sites, seedlings with low shoot-root ratios survive well because (1) desiccation and increase in moisture stress immediately after planting are minimized, and (2) subsequently internal water stress is low enough to permit some root growth, which further increases the absorptive capacity of the root system. The beneficial effects of increased root growth are somewhat offset by the increased shoot growth, but the net effect obviously is beneficial, as evidenced by the increased survival.

Because we used only one lifting and planting date we do not know the influence of date of lifting or length of storage. However, these factors are known to have a considerable effect on root growth and survival (Lavender 1964).

Since survival can be increased by planting seedlings with low shoot-root ratios, it would be desirable for nurseries to give greater emphasis to shoot-root ratio in growing and grading seedlings. In practice, visual grading may be satisfactory. After undersized or damaged seedlings and those with obviously poor root systems are discarded, remaining seedlings could be separated into two root sizes. This would permit planting the seedlings with the largest roots on the droughty sites and retaining average stock for more moderate sites.

We also emphasize the need to grade seedlings by shoot-root ratio in field tests designed to evaluate seedling response to environmental factors, because it is obvious that differences in shoot-root ratio could minimize or mask influence of other treatments.

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

A 13.79:PNW-275

PNW-275

August 1976

SEX IDENTIFICATION OF ADULTS AND PUPAE OF A BIRCH DEFOLIATOR, *RHEUMAPTERA HASTATA*, IN INTERIOR ALASKA

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NOV 10 1976
U.S. DEPT. OF AGRICULTURE

by

Richard A. Werner, *Research Entomologist*

ABSTRACT

A method is described for determining the sex of adults and pupae of *Rheumaptera hastata* (L.) based on external sexual characteristics such as shape of abdomen and location of genital openings.

KEYWORDS: *Rheumaptera hastata*, reproductive organs (insect), birch, Alaska.

GOVT DOCUMENTS
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FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

Populations of the spear-marked black moth, *Rheumaptera hastata* (L.) have reached epidemic levels in birch forests of interior Alaska in 1974 and 1975. Investigation of the life cycle and reproductive behavior could not be accomplished accurately without some method of differentiating the sexes. This paper describes a method for identifying sex in both pupae and adults. Similar methods of sex determination were reported by Yates (1969), Jennings and Acciavatti (1975), and Butt and Cantu (1962) for other lepidopterous pupae.

Pupal sexual characteristics can be distinguished only under a microscope (25X) and are confined to the terminal abdominal segments. The primary difference between the sexes is the location of the genital opening. In male pupae, the genital opening is located ventrally on the 9th abdominal segment (fig. 1A) 0.21 ± 0.02 mm anterior to the anal opening located on the 10th abdominal segment. The female genital opening is located on the 8th abdominal segment (fig. 1B) 0.51 ± 0.05 mm anterior to the anal opening also located on the 10th abdominal segment.

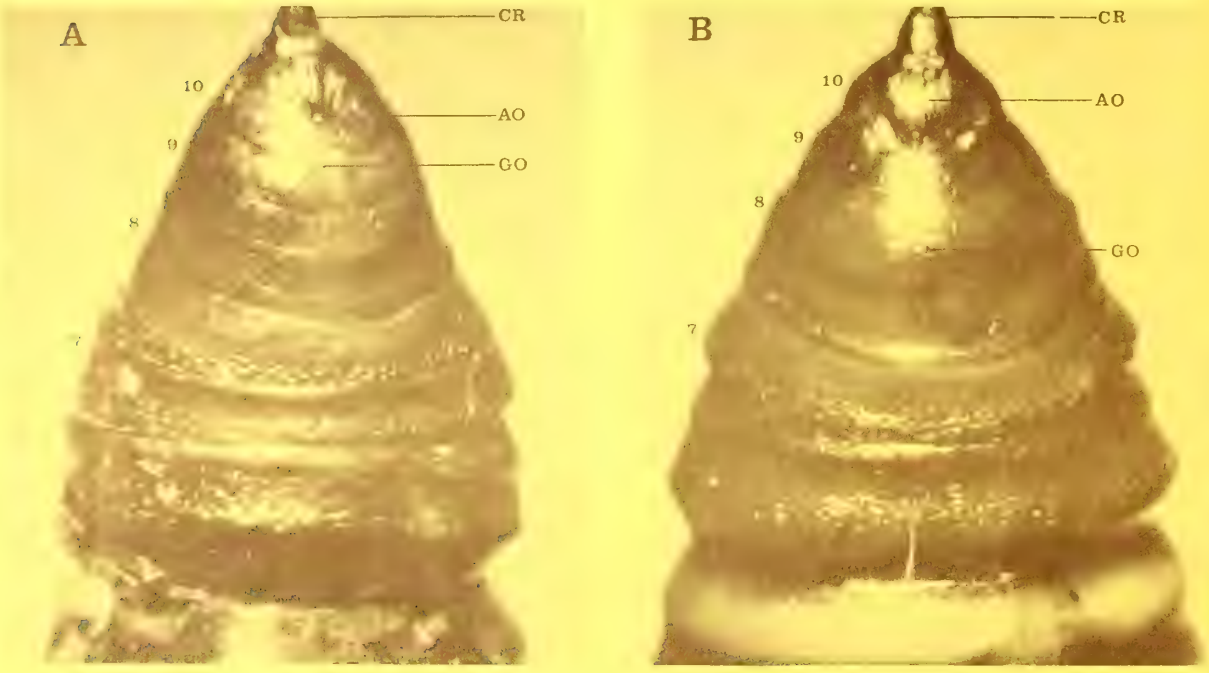

Figure 1.--Ventral abdominal view of (A) *male and* (B) *female pupae of* R. hastata *showing GO, genital opening; AO, anal opening; CR, cremaster; and abdominal segments 6-10.*

Sexual characteristics of adults are discernible without magnification, and field identification can be made readily by examining the terminal abdominal segments. In males, the last visible terminal abdominal segment is the eighth, which appears elongated and is bisected in a dorsal-ventral plane (fig. 2A). This segment encloses the 9th and 10th genital segments. The 7th abdominal segment is the last visible segment in female adults and encloses the 8th, 9th, and 10th genital segments. The valvulae of the ovipositor can often be seen extruding from the 7th abdominal segment (fig. 2B). Slight pressure with the fingers on the last visible abdominal segments of both sexes will reveal the normally retracted genital segments.

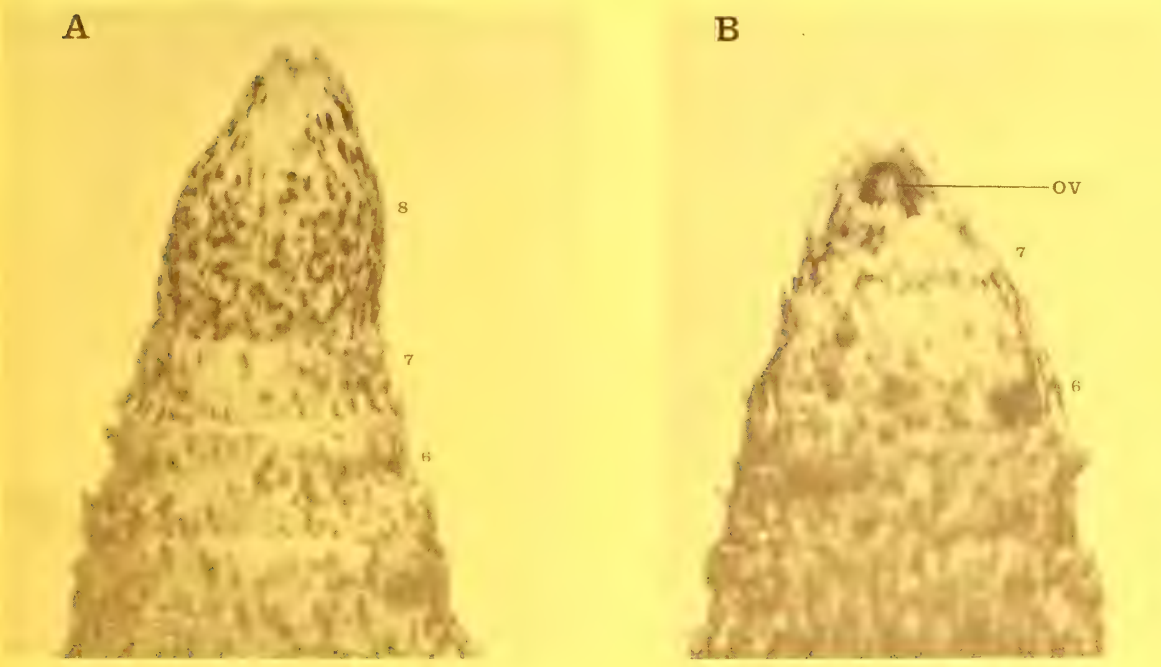

Figure 2.--Dorsal abdominal view of (A) *male and* (B) *female adults of* R. hastata *showing abdominal segments 7-10 and the OV, ovipositor of the female.*

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GPO 996-953

ALASKA OREGON WASHINGTON

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-276 September 1976

ERRORS FROM APPLICATION OF WESTERN HEMLOCK SITE CURVES TO MOUNTAIN HEMLOCK

by

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and

Jerry F. Franklin, *Chief Plant Ecologist*

GOVT. DOC. DEPOSITORY

ABSTRACT

Application of coastal western hemlock site curves to mature and overmature mountain hemlock stands may lead to large errors in estimation of growth and yield. Overestimation of site by 25 feet (7.6 m), for example, leads to volume estimation errors of 60 to 240 percent depending on volume tables and minimum diameters selected.

KEYWORDS: Site index -)stand height/age, volume estimation -)yield tables, mountain hemlock, *Tsuga mertensiana*, western hemlock, *Tsuga heterophylla*.

NOV 89

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

Forests dominated by mountain hemlock (*Tsuga mertensiana*) cover thousands of acres at high elevations in the Pacific Northwest. Nearly pure, apparently even-aged mountain hemlock stands are common in the high Cascades of southern Washington and central and southern Oregon (Franklin 1965) where they are often included in the commercial forest-land base. However, foresters charged with managing these lands are frustrated by an absence of data on which to base growth and yield predictions and prescribe silvicultural treatments. Neither site index curves nor yield tables are available for mountain hemlock.

Some land managers are using western hemlock (*Tsuga heterophylla*) site curves and yield tables (Barnes 1962) as interim guides to growth and yield of mountain hemlock. It is unlikely that those curves and tables accurately estimate productivity in either high-elevation western hemlock or in higher elevation mountain hemlock growing in the Cascade Range of Oregon and Washington. Barnes' tables are based entirely within the coastal fog-belt range of western hemlock. No Cascade stands were investigated.

Stem analysis data recently collected from 11 dominant and codominant mountain hemlocks provided us with the first detailed growth information for the species. Height growth patterns from those 11 mountain hemlocks were compared in this research with existing western hemlock site curves. The actual height of each of those trees at 100 years is compared with the height predicted from the western hemlock site curves based on total age and height. Although our sample is small, the large and consistent overestimation of site index that results from the use of the western hemlock site curves in old-growth mountain hemlock warrants this report.

METHODS

In the course of preparing site curves for noble fir (*Abies procera*) (DeMars et al. 1970), dominant and codominant specimens of associated trees occurring in the same plots were felled and sectioned. Eleven dominant and codominant mountain hemlocks were included from 10 different plots, mostly on the northern Mount Hood National Forest (table 1). The trees selected were the tallest sound, free-growing mountain hemlocks--free of visible defects, such as breaks or large forks. Field and laboratory stem analysis methods used are described in Herman and DeMars (1970) and Herman et al. (1975). Trees were felled and typically sectioned at breast height and at irregular intervals up the stem--every 8 to 10 feet (2.5 to 3.0 m) for small trees and 16 to 18 feet (5 to 5.5 m) for large trees. Disks from each section were brought into the laboratory for detailed ring analysis.

Graphs of height over age developed from stem analyses are the basic data for this report. Total height above ground and age at stump and breast height were determined directly. Total age was estimated by projecting the stump to breast height growth rate back to the ground line. Height at 100 years was read from the height-age graphs. Total age and height of the mountain hemlocks were used on the western hemlock site index alinement chart (Barnes 1962, p. 5) to obtain a predicted site index or height at 100 years.

Table 1--*Comparison of actual height of 11 mountain hemlocks with predicted height at 100 years using western hemlock site curves*

Plot location	National Forest	Elevation	Crown class[1]	Age at b.h.	Total age[2]	Total height	Height at 100 years	Predicted height at 100 years[3]	Error in prediction
		- Feet -		*- - - Years - - -*		*- - - - - - - - Feet - - - - -*			
Timberline	Mount Hood	4,348	Dom	232	237	112	64	92	+28
Hood River Meadows	Mount Hood	4,392	Dom	260	266	126	85	100	+15
Upper Pocket Creek	Mount Hood	4,595	CoD	221	240	86	52	70	+18
Lower Pocket Creek	Mount Hood	2,394	CoD	246	257	150	86	120	+34
Wahtum Lake	Mount Hood	4,303	Dom	191	201	79	48	66	+18
North Wilson	Mount Hood	4,663	CoD	235	241	101	67	84	+17
Milepost 64	Mount Hood	3,926	CoD	263	274	106	40	86	+46
			CoD	273	284	96	30	77	+47
Fawn Meadow	Mount Hood	4,522	CoD	189	212	121	66	100	+34
Wildcat Mountain #1	Willamette	4,700	CoD	192	206	102	65	86	+19
Wildcat Mountain #2	Willamette	4,680	CoD	203	207	101	65	84	+21
Average for 10 areas[4]		4,452	--	224	235	108	63	88	+25

[1] CoD = codominant and Dom = dominant.

[2] Determined by projecting growth rate between breast height and stump height (actual ages determined at each location) back to average ground line. Actual total ages are probably somewhat greater.

[3] Site index or height at 100 years from western hemlock site index alinement chart based on total height and age of trees (Barnes 1962).

[4] Two trees at Milepost 64 averaged for single plot values.

RESULTS

Western hemlock site curves grossly overestimate site index or height at 100 years for these 11 mountain hemlocks (table 1). The average predicted height at 100 years is about 25 feet (7.6 m) or over one-third greater than the actual height. The 11 trees, which range in age from 201 to 284 years, have errors of +15 to +47 feet (4.6 to 14.1 m).

Typical height growth graphs for mountain hemlock and curves for western hemlock for site index 60 to 110 are shown in figure 1. The deviation between predicted and actual values for height at 100 years is clearly a consequence of slower height growth in youthful mountain hemlock coupled with prolonged growth into later life. This is similar to the height growth pattern observed in Douglas-fir at high elevations compared with lower elevations (Curtis et al. 1974).

None of the mountain hemlock exhibited any early suppression at stump height. Early growth was slow but steady in all cases. Trees at Milepost 64, which showed the greatest variance from the western hemlock site curves, provided an extreme example of an almost constant rate of height growth until they were felled at 263 years of age (fig. 1).

DISCUSSION AND CONCLUSIONS

Application of western hemlock site curves to mature and overmature mountain hemlock stands indicates unacceptable errors in estimation of growth and yield (table 2). The overestimation of site index by 25 feet (7.6 m) leads to errors at index age of 100 years; errors range from 60 to 85 percent in cubic-foot and 120 to 240 percent in board-foot volumes, depending on the minimum diameter used. This assumes, of course,

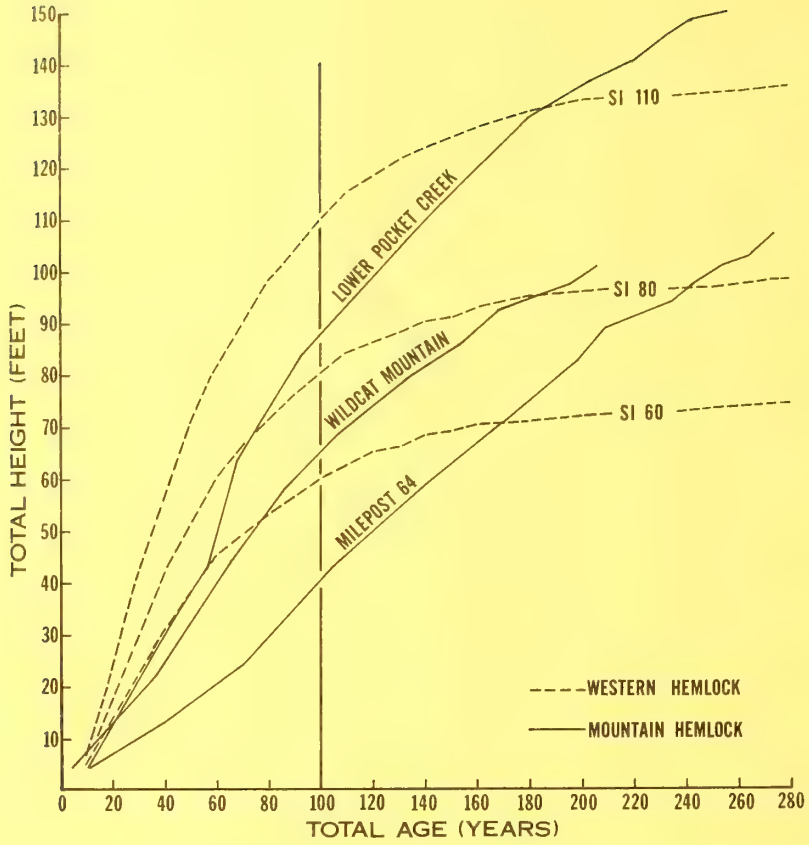

Figure 1.--Height-over-age curves for mountain hemlocks on three representative plots compared with Barnes' (1962) western hemlock site curves.

Table 2--*Comparison of estimated stand volumes per acre using actual height at 100 years and predicted height based on western hemlock site curves*[1/]

Item	Values based on		
	Actual height at 100 years	Predicted height at 100 years	Overestimation from western hemlock site index
			Percent
Height in feet (meters)	63 (19.2)	87 (26.5)	40
Western hemlock site class[2/]	VI	V	--
Volume per acre at 100 years[2/]			
Cubic feet in trees >1.5-inch d.b.h. (cubic meters)[3/]	6,310 (179)	9,990 (283)	58
Cubic feet in trees >6.5-inch d.b.h. (cubic meters)[3/]	4,968 (141)	9,130 (258)	84
Board feet, International 1/4-inch rule, in trees >6.5-inch d.b.h. [4/]	24,000	52,000	117
Board feet, International 1/4-inch rule, in trees >11.5-inch d.b.h. [4/]	10,000	34,000	240

[1/] Site curves from Barnes (1962).

[2/] From Barnes (1962). Estimated volumes interpolated from tables for British Columbia western hemlock because tables for Oregon and Washington do not include site classes V and VI.

[3/] Converted to cubic meters from cubic feet.

[4/] There is no single conversion to cubic meters from board feet.

that expected volumes in fully stocked mountain hemlock stands at 100 years are the same as for western hemlock stands of the same height.

Even with the correct western hemlock site index (height at 100 years), the western hemlock yield tables will not accurately estimate yields for mountain hemlock. For a given site index, growth and yield of young (<100 years old) mountain hemlock stands will almost certainly be less than in comparably aged coastal western hemlock stands because of slower growth rates and lower stocking levels. At 100 years, even if the mountain hemlock stand had stocking levels and average diameters similar to those in the western hemlock yield tables, a lower form factor for mountain hemlock might be expected to result in volumes below those shown in the western hemlock yield tables. Stem taper[1/] of mountain hemlock was consistently greater than that for western hemlock growing on comparable sites. Form quotient for the 11 mountain hemlocks averaged 64 and that for 10 comparable Cascade Range western hemlocks averaged 71.[2/]

The sustained growth of mountain hemlock could result in growth and stand volumes after 100 years which gradually surpass those shown in the western hemlock yield tables for a given site index or height at 100 years. Much of the volume often observed in old-growth mountain hemlock stands probably developed in the last half of their lives.

Deviations of mountain hemlock from western hemlock site curves may be even greater, on the average, than is indicated by our study trees. These trees are from sites relatively low in mountain hemlock's elevational range and from stands considered clearly "commercial." At higher elevations, particularly close to the upper limits of subalpine forest, early growth rates will be even slower.

Given the inapplicability of western hemlock site indices to mountain hemlock, what can the forester do to fill the present information gap? Obviously, whenever mountain hemlock is not a predominant stand component, he can utilize other species for which valid site index curves are available for estimating relative productive potential. When they are not available, the land manager can:

1. Develop local site curves and yield tables. Stem analyses will almost certainly be essential unless a good range of age classes on essentially identical sites is available for installation of temporary plots. Obtaining good ratio estimates of total age or years to breast height is critical because of the slow growth of mountain hemlock, especially near upper timberline.

[1/] Stem taper herein is defined as form quotient (the stem diameter inside bark at halfway point between ground and tree tip divided by diameter breast height inside bark).

[2/] The western and mountain hemlocks were from different plots but noble fir site index was essentially the same (81 and 80, respectively); elevation did differ--western hemlock plots averaged 3,500 feet (1 065 m) and mountain hemlock plots 4,450 (1 355 m).

2. If (1) is not possible, a crude adjustment of the western hemlock yield tables for mountain hemlock can be made by adjusting predicted site index downward, depending on the age of the stand. The reduction should be about 25 feet (7.6 m) for the predicted 100-year height for mountain hemlocks 200 to 300 years old. At least 10 years should be allowed for growth to breast height.

When final noble fir site curves are available, it may be possible to use the relationship between mountain hemlock and noble fir growth to estimate mountain hemlock site index. Estimates of productivity in mountain hemlock stands, and probably upper-slope western hemlock stands as well, will continue to be crude until appropriate site curves and yield tables can be developed.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

aS3.79:PNW-277 OCT 27

PNW-277 July 1976

DIURNAL TEMPERATURE REGIMES OF LOGGED AND UNLOGGED MIXED CONIFER STANDS ON ELK SUMMER RANGE

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by

Paul J. Edgerton, *Wildlife Biologist*

and

Burt R. McConnell,[1/] *Principal Wildlife Biologist*

ABSTRACT

Temperature profiles for unlogged, partial-cut, and clearcut stands showed that removal of all or a portion of the tree canopy resulted in cooler nights and warmer days. Range of temperature extremes was greatest in the clearcut and least in the unlogged stand. Differences in canopy cover between the unlogged and partial-cut stands were relatively small, but there was a noticeable difference in thermal regimes. Daytime temperatures in the partial-cut stand were warmer, but nocturnal temperatures were somewhat cooler than in the unlogged stand. These differences influence selection of thermal cover by elk.

KEYWORDS: Temperature -)partial cutting, temperature -)clear-cutting, temperature (-wildlife habitat, Rocky Mountain elk.

[1/] Burt R. McConnell is now with Pacific Southwest Forest and Range Experiment Station, Institute of Pacific Islands Forestry, Honolulu, Hawaii.

Logging is dramatically changing the character of Rocky Mountain elk (*Cervus canadensis nelsoni*)[2/] summer ranges in mixed conifer forests of northeastern Oregon. Biologists are concerned that increased human activity coupled with the rapid harvest of old-growth timber stands, which provide essential cover for hiding and thermal comfort, will significantly lower the suitability of these ranges for elk. Research is underway in several Western States to determine animal response to different timber management practices and to develop alternatives that will insure a balance of suitable habitats.

Influence of the temperature regime on ungulate behavior is well known (Beall [in press], Loveless 1967, Moen 1973). Elk respond to environmental temperatures in various ways (e.g., changes in orientation, posture, or activity), but selection of cover is probably the most effective means of adjusting the balance between heat loss and heat production. The importance of protective cover during winter is well documented, but the use of cover for thermal comfort in summer is not fully appreciated. There is a need for environmental data to better understand the influence of silvicultural treatments on elk behavior. This note compares diurnal temperature patterns in adjacent unlogged, clearcut, and partial-cut mixed conifer stands during the June-September period.

THE AREA

The study area is located approximately 12 miles (19 km) west of Troy, Oregon (latitude 45°56', longitude 117°36'), at 4,000-foot (1 200-m) elevation. Annual precipitation is estimated to be 30-40 inches (75-100 cm) and occurs mainly as winter snow and spring and fall rains. Topography is a gently rolling plateau bounded by deep canyons. Elk, or their signs, are observed frequently from early May through late November. Physical characteristics of the study sites are listed in table 1.

The unlogged study site (fig. 1) was a representative 200-year-old, mixed conifer stand approximately 820

Table 1--*Characteristics of termperature profile study sites in a mixed conifer forest, northeastern Oregon*

Site	Aspect	Slope	Stand basal area	Stand density	Canopy cover (stand average)
		Percent	*ft^2/acre (m^2/ha)*	*Stems/acre (stems/ha)*	*Percent*
Unlogged	SE	14	229 (52.6)	401 (1 000.8)	94
Clearcut	ESE	12	0	0	0
Partial-cut	ESE	15	171 (39.2)	430 (1 178.7)	83

[2/] Sources for scientific nonmenclature are Little (1953), Hitchcock et al. (1955-69), and Ingles (1965).

Figure 1.--Unlogged study site.

Figure 2.--Clearcut study site.

feet (250 m) wide surrounding a 39-acre (15.8-ha) clearcut (fig. 2). It is dominated by grand fir (*Abies grandis*), with lesser amounts of western larch (*Larix occidentalis*), Douglas-fir (*Pseudotsuga menziesii*), Engelmann spruce (*Picea engelmannii*), lodgepole pine (*Pinus contorta*), and occasional ponderosa pine (*Pinus ponderosa*). The understory is mostly big huckleberry (*Vaccinium membranaceum*). Several other low shrubs, many shade-tolerant forbs, and occasional sedges and grasses are also present.

After logging in 1963-64, slash and cull logs were left untreated in the clearcut and the unit was planted with ponderosa pine and seeded to grass.

The nearby partial-cut site (fig. 3) was part of an extensive tract of mixed conifer forest selectively logged in 1964. Only the larger trees were removed, so the harvest was relatively light. In addition, the stand had a wider distribution of ages than the unlogged area, so scattered groups of smaller trees remained undisturbed after logging. Disturbance of soil and vegetation was not as extensive as in the clearcut; invasion by seral forbs and shrubs was largely confined to spur roads, deck areas, and skid trails.

Figure 3.--Partial-cut study site.

METHODS

Temperatures were recorded during the 1967 and 1969 growing seasons at the center of 2-acre (0.81-ha) plots located at comparable midslope positions in each study site. Thermographs were placed 18 inches (45.7 cm) above the forest floor in small shelters similar to those designed by Hungerford (1957). The data were taken at the top of the shrub-herb understory primarily to supplement a companion plant succession study; temperatures at midbody height of standing animals would be expected to be slightly cooler and less variable. No statistical analyses were made because of sample size limitations, but the consistent thermal patterns in figure 4 suggest that reasonable comparisons between treatments can be supported.

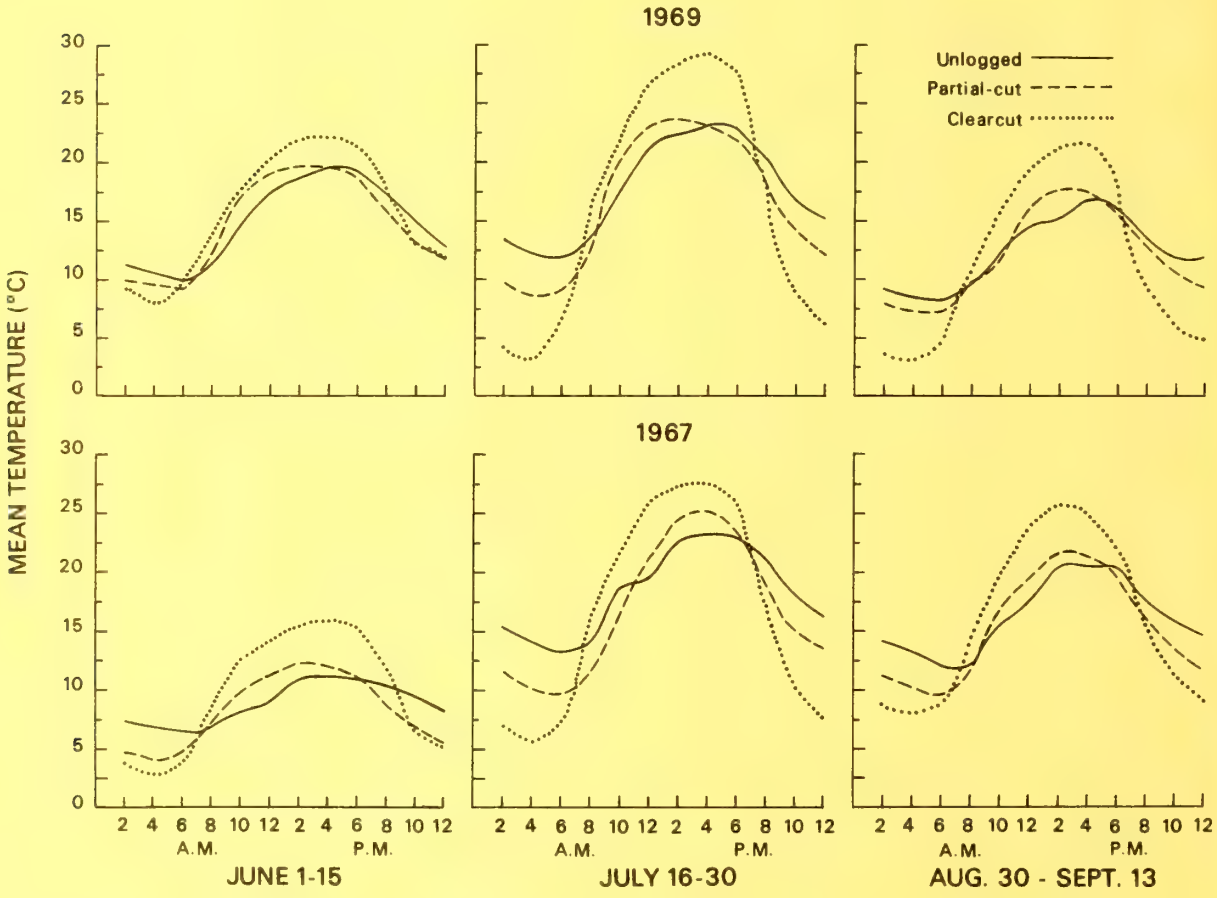

Figure 4.--Diurnal temperature profiles for unlogged, partial-cut, and clearcut mixed conifer forest, northeastern Oregon.

RESULTS AND DISCUSSION

Diurnal temperature patterns for representative early-, mid-, and late-summer periods are summarized in figure 4. Seasonal differences are clearly reflected. In early summer, average temperatures are cooler, with frequent periods of cloudiness and precipitation. As the summer progresses, the frequency of precipitation declines. Days are quite warm, but nocturnal temperatures drop quickly due to clear skies and low humidity. By late summer and early fall, daytime maximums are lower, and unsettled weather increases.

As figure 4 shows, the relationships between temperature profiles on the three sites were consistent throughout the seasons. Temperature extremes were greatest in the clearcut and least in the unlogged stand. Tree canopies of the timbered sites reduced both incoming and outgoing radiation, thereby moderating these environments. This effect was most pronounced during midsummer under clear skies; during early summer, differences were minimized by clouds which limited radiation loss.

The difference in canopy cover between the unlogged and partial-cut sites was relatively small, yet there was a noticeable difference in thermal regimes. Daytime temperatures in the partial-cut stand were warmer, but nocturnal temperatures were somewhat cooler than in the unlogged stand. Geiger (1965) explains that most of the radiation exchange in forests with unbroken canopies occurs at crown tops because the canopy prevents significant penetration by sun and wind. In logged or thinned forests, gaps in the canopy allow greater daytime heating and air circulation near the forest floor. Conversely, at night, heat radiated from the forest floor escapes more quickly to the open sky. Silvicultural prescriptions, such as the shelterwood or seed tree systems, that remove a much greater portion of the canopy would be expected to create environments with temperature profiles approaching that of the clearcut.

General observations indicate that old-growth mixed conifer stands of suitable size and distribution are a necessary component of elk summer range in northeastern Oregon. Edgerton (1972) reported that 5 years after logging, elk pellet group densities were highest in the clearcut and lowest in the partial-cut area. Forage was the obvious attraction in the clearcut. The adjoining unlogged area lacked preferred forage plants, and the presence of numerous well-used bedding areas and trails indicated that its primary value was concealment and thermal comfort for resting animals. The partial-cut stand provided neither optimum forage nor cover during this period.

Figure 4 suggests that the comparatively stable environment of unlogged stands is probably an important factor in habitat selection by elk. Thus, during cold, wet periods in the spring and fall, elk undoubtedly seek shelter in these stands to minimize loss of body heat. On warm summer days, cooler temperatures are the obvious attraction. This is confirmed by telemetry studies[3/] in an adjacent area which showed that during the summer, elk used clearcut areas at night but preferred the security and milder temperatures of dense conifer stands during the day. Movement of elk between habitats generally occurred during warming and cooling periods in the early mornings and evenings.

3/ Personal communication with R. J. Pedersen, Oregon Department of Fish and Wildlife, January 1976.

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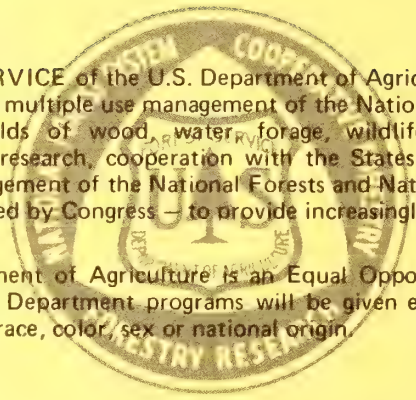

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

A 13.79:PNW-278

PNW-278 October 1976

GOVT. DOCUMENTS DEPOSITORY ITEM

DWARF MISTLETOE INFECTION FROM RESIDUAL WESTERN HEMLOCK ON CUTOVER STANDS

by

J. L. Stewart [1/]

ABSTRACT

The percentage of dwarf mistletoe-infected hemlock trees within 30 ft of an infected residual overstory tree increased rapidly with age of the stand. Infected unmerchantable trees should therefore be destroyed during or as soon after harvest as is possible.

KEYWORDS: Parasites (plant) (- forest damage, dwarf mistletoe, *Arceuthobium tsugense*, western hemlock.

Until recent years, hemlock dwarf mistletoe was generally not considered an important problem by most forest managers. Infected residual trees were not removed during or after clearcutting. As a result, regenerated stands on thousands of acres of Federal, State, and private lands are now becoming infested with dwarf mistletoe from residual trees. Smith (1966) stated that as few as 10 evenly spaced infected residual trees per acre are sufficient to reinfest the trees on an entire acre. Land managers, responding to recent publications (Shea and Stewart 1972, Smith 1969) and efforts by pest control pathologists, now want to remove residual infested trees. This raises the question--when do the new stands become so infested that it no longer pays to make a special entry into the stand to remove the residuals?

[1/] At the time this research was conducted the author was Project Leader at the Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon. He is now Director of Forest Insect and Disease Management, USDA Forest Service, Washington, D. C.

Hawksworth and Graham (1963), working with lodgepole pine, showed the percentage of understory trees infected to be correlated with stand age. This paper reports an attempt to correlate the percentage of infected young hemlock with stand age.

Methods and Materials

Transects, 10-ft-wide by 30-ft-long, radiating from the bases of infected residual overstory trees, were established in pure hemlock stands ranging in age from 10 to 25 years. Smith (1966) shows that over 95 percent of the mistletoe seeds dispersed from an overstory tree fall within 35 ft of the tree. Density varied from 725 trees per acre in the lightest stocked transects, to 18,705 trees per acre in the most heavily stocked transects. The stands were located on lands managed by the Bureau of Indian Affairs, U.S. Forest Service, and Crown-Zellerbach Corporation in western Washington and Oregon. A total of 39 overstory trees and 52 transects were used. Data were averaged when there was more than one transect for an individual overstory tree.

Each tree within a transect was examined for the presence of dwarf mistletoe shoots. Stand age was determined by counting annual rings of a few trees cut at the ground line.

Results and Discussion

Within 30 ft of an infected residual overstory tree, the percentage of trees visibly infected with dwarf mistletoe increases with age of the stand (fig. 1). Although the relationship is highly

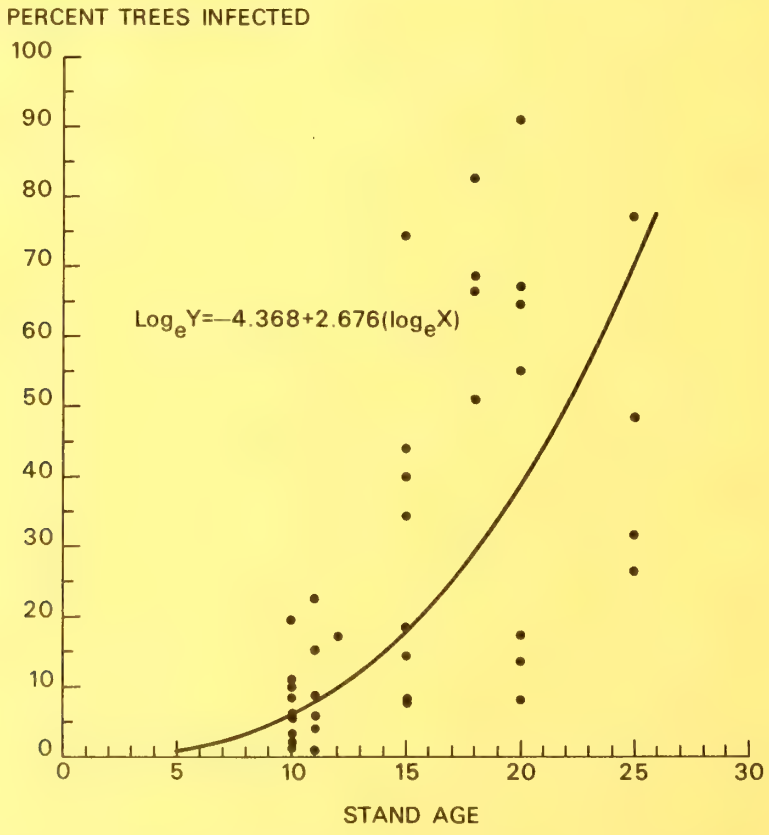

Figure 1.--Percentage of infected trees within 30 ft of a residual infected overstory tree by age of the stand.

significant, less than 50 percent of the variation is accounted for by stand age. The unaccounted variation could be due to other factors influencing infection such as stand density, tree size, or inoculum in overstory trees. These factors were not included in the analysis because of extreme variation. Although the equation, $\log_e Y = -4.368 + 2.676 (\log_e X)$, cannot be used as a precise estimator of percentage of trees infected, it does show the trend of rapid increase in percentage of trees infected with stand age. The equation stresses the importance of eliminating all infected residuals at or soon after the time of harvest.

In stands 20 years and older, residual overstory trees were difficult to locate because of the density and height of the stand. Barnes (1962) gives the average height of dominant and codominant trees at 20 years on site index 150 as 31 ft. In such stands, residuals could be spotted from roads, on aerial photos, or from opposite slopes--but only with great difficulty from within the stand. Under these circumstances, residual tree removal is impractical except when done during thinning or other cultural operations.

Residual tree removal as a separate operation is practical in stands 15 to 20 years of age or younger; but even in these stands, it may be advantageous to combine residual tree removal with precommercial thinning. Priority for residual tree removal depends on the manager's objective for the area. Youngest stands should have priority if the goal is to reduce dwarf mistletoe infection to a minimal level on as many acres as possible. Older stands should have priority if the goal is to prevent infection from reaching moderate levels. The number and distribution of residuals per acre should also be a criterion for setting priorities in stands under 20 years of age. Stands with a greater number of residuals per acre should be given higher priority than those with fewer residuals.

Acknowledgment

Appreciation is given to the Bureau of Indian Affairs, U.S. Department of the Interior, and to Crown-Zellerbach Corporation for their assistance in this study.

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USDA FOREST SERVICE RESEARCH NOTE

13.79: PNW-279

PNW-279

October 1976

SHRUB PLANTINGS FOR EROSION CONTROL IN EASTERN WASHINGTON--PROGRESS AND RESEARCH NEEDS

by

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Glen O. Klock, *Principal Soil Scientist*[1/]

Lee L. Mason, *Nursery Superintendent*[2/]

Donald E. Sears, *Forestry Technician*[2/]

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ABSTRACT

In August 1975, survival measurements and vigor estimates were made on 14 species of shrubs planted on road cut and fill slopes between 1971 and 1973 on the Wenatchee, Okanogan, and Colville National Forests. Their average survival ranged from 37 to 53 percent and was better at low than high elevations and greater on fill slopes than cut slopes.

Of species planted on enough sites to enable a good assessment of survival, blue elderberry, bush penstemon, wild rose, and serviceberry had the highest survival. Vigor of blue elderberry and penstemon was good, but vigor of wild rose and serviceberry was only fair to poor.

Survival rate of bitterbrush, squaw carpet ceanothus, and snowbrush ceanothus was reduced on cut slopes because plants were covered by ravelling soil material. However, good survival and growth of these plants on fill slopes indicate they can probably be used successfully on many sites of this type.

KEYWORDS: Erosion control -)vegetal cover, vegetation types, shrubs, native plants.

[1/] Pacific Northwest Forest and Range Experiment Station.

[2/] Coeur d'Alene Forest Nursery, USDA Forest Service, Coeur d'Alene, Idaho.

Natural revegetation of road construction cuts and fills and other severely disturbed wildland sites in the Pacific Northwest is often a slow process. Highly disturbed areas without vegetative cover have low esthetic value and are susceptible to erosion. Seeding of disturbed areas with grasses and legumes to provide protective vegetative cover has been recommended in the Pacific Northwest by Dyrness (1967, 1970) and Klock et al. (1975). However, soil and microclimatic conditions of many planting sites in the interior Pacific Northwest limit the use of common grasses and legumes. Disturbed sites are characterized by loose, droughty soils depauperate in plant nutrients. They are also characterized by extremes of soil and air temperatures and frequent soil movement resulting from frost action and dry rattle. Shrubs have been shown to stabilize such arid and harsh areas (Horton 1949, Plummer 1974, McArthur et al. 1974, McKell 1975).

In 1970 the Coeur d'Alene Forest Nursery in Idaho initiated a program for growing and test planting native shrubs to stabilize and beautify road cuts and fills and other disturbed wildland sites in the Pacific Northwest. Shrubs from the nursery have been used since 1971 for planting trials on the Wenatchee, Okanogan, and Colville National Forests in the State of Washington.

We evaluated these initial plantings to make an early assessment of species that can be used operationally, to recommend planting techniques, and to determine immediate research needs.

METHODS

In October 1973, 1-year-old, bare-root shrub seedlings from the Coeur d'Alene Nursery were planted on newly constructed road cutbanks and fills in the Entiat Experimental Forest and adjacent Wenatchee National Forest lands in the Entiat Valley. Six to ten species were planted in 4 to 10 blocks at 12 locations. Within blocks, five to seven plants of an individual species were planted in a single row spaced at 1 meter between plants and adjacent rows. The seedlings were planted with a hoedag or flat spade from a 6-meter aluminum extension ladder laid upslope. The ladder gave the planter quick and easy access for planting two rows and kept site disturbance during the planting operation to a minimum. The soils on sites 1 and 2 were colluvium subsoil derived predominantly from granodiorite parent material. The other 10 plantings were in decomposed granodiorite, volcanic ash, highly unstable "popcorn" pumice, or mixtures thereof. Organic matter and plant nutrient content were extremely low on all sites. Slope steepness ranged from 40 to more than 70 percent. Good soil moisture conditions prevailed at all locations at planting time. Species planted were:

Wenatchee National Forest	Growth habit[3/]
Oregongrape (*Berberis repens* Lindl.)[4/]	Low, trailing shrub usually less than 1 m tall.
Bush penstemon (*Penstemon fruticosus* (Pursh) Greene)	Ascending or erect, bushy branched shrub or subshrub, 0.5 to 1 m tall; spreads laterally by layering and may form mats to 1 m in diameter.
Squaw carpet ceanothus (*Ceanothus prostratus* Benth.)	Prostrate or matlike shrub, 1 to 3 m across; roots by layering.
Snowbrush ceanothus (*Ceanothus velutinus* Dougl.)	Compact shrub, 1 to 2 m tall, evergreen, symbiotic nitrogen fixer, susceptible to winter dieback on exposed sites.
Sedgeleaf buckbrush (*Ceanothus cuneatus* (Hook.) T. & G.)	Rigid, many-branched evergreen shrub, 1 to 4 m tall.
Redstem ceanothus (*Ceanothus sanguineus* Pursh)	Erect, open shrub, 1 to 2 m tall.
Serviceberry (*Amelanchier alnifolia* Nutt.)	Erect, many-stemmed shrub or small tree, 1 to 6 m tall.
Bitterbrush (*Purshia tridentata* (Pursh) DC.)	Diffusely branched, semierect shrub, 0.3 to 2 m tall.
Blue elderberry (*Sambucus cerulea* Raf.)	Coarse, many-stemmed shrub or small tree, 1 to 6 m tall.
Snowberry (*Symphoricarpos* sp.)	Erect shrub, 0.6 to 1.2 m tall, spreads by rhizomes.

The seed sources for these shrubs were not from the local planting area; but with the exception of squaw carpet ceanothus and sedgeleaf buckbrush, all species can be found in the Entiat Valley. No chemical fertilizer amendments were used on any of the plantings.

Bare-root shrubs from the Coeur d'Alene Nursery were planted in the fall on road construction cut slopes on the Colville National Forest in

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[3/] From U.S. Department of Agriculture (1937), Hayes and Garrison (1960), Hitchcock et al. (1955-69).

[4/] Plant nomenclature follows Hitchcock and Cronquist (1973).

1971 and 1973 and on the Okanogan National Forest in 1973. Nine locations on each Forest were chosen for evaluation. Species planted were:

Colville National Forest	Growth habit
Serviceberry	
Bitterbrush	
Wild rose (*Rosa* sp.)	Spreading shrubs 1 to 2 m tall, sprouts from shallow subsurface root system and forms dense thickets.
Curl-leaf mountain mahogany (*Cercocarpus ledifolius* Nutt.)	Shrub or small tree 0.3 to 4 m tall.
Snowberry	
Smooth sumac (*Rhus glabra* L.)	Many-stemmed shrub, 1 to 3 m tall, spreads by elongate, shallow roots and forms dense thickets.

Okanogan National Forest	Growth habit
Oregongrape	
Bush penstemon	
Bitterbrush	
Wild rose	
Curl-leaf mountain mahogany	
Chokecherry (*Prunus virginiana* L.)	Erect shrub or small tree, 1 to 10 m tall.
Kinnikinnick (*Arctostaphylos uva-ursi* (L.) Spreng.)	Low, prostrate evergreen, often forming mats to 2 m in diameter.

With the exception of curl-leaf mountain mahogany, these shrubs were grown from seed collected in the general area of the plantings. Curl-leaf mountain mahogany is found principally from southeastern Washington to California.

In August 1975 we evaluated survival and vigor of all plantings. Vigor was based on size of plant and color of foliage and was classed as good, fair, or poor. Complete records of survival were kept on the Wenatchee National Forest plantings. The Colville and Okanogan National Forest plantings were established without a complete record of the number of plants of each species planted at each location. Therefore, some reconstruction of plant spacing was necessary for estimating survival. In some cases,

survival data are estimates made by the individual who supervised the plantings.

RESULTS AND DISCUSSION

Survival data from the planting trials reveal several shrub species with potential for use in disturbed area revegetation programs in the interior Pacific Northwest.

WENATCHEE NATIONAL FOREST SITES

The broad array of conditions on the Wenatchee National Forest enabled us to assess survival of shrubs planted there as a function of aspect, elevation, and type of sites (road cut or fill). After 2 years survival of all species on all sites on the Wenatchee National Forest averaged 38 percent. Elevation (range 755- to 1 478-m) appeared to have little effect on total survival. Slightly higher survival was observed on southerly and easterly aspects than on westerly aspects. No plantings were made on north aspects. The greatest site difference for survival was between road cuts (33 percent) and road fills (55 percent). Differences in depth, texture, stability, and moisture-holding capacity of the soil material between the cuts and fills probably account for this difference.

Average survival of individual species on the Wenatchee National Forest ranged from 13 percent for bitterbrush to 75 percent for blue elderberry (table 1).

Survival of blue elderberry was consistently high (62 to 87 percent), and this species displayed good vigor on all locations. Its tough stems along with its rapid growth rate provided an important advantage on unstable, "popcorn" pumice road cuts. We were especially pleased with elderberry survival and growth since the 1-year-old seedlings we planted were quite large, and we had to severely prune the root systems on many plants to facilitate planting.

Bush penstemon survival was 40 percent or greater at all sites except 5 and 9, where many plants were buried by pumice. Vigor of the surviving plants was good, and this species should show a positive response to fertilization (Klock 1976).

Survival of Oregongrape was low and vigor fair to poor. Survival of bitterbrush, snowbrush ceanothus, squaw carpet ceanothus, and sedgeleaf buckbrush was generally low. However, surviving plants of these species had good vigor on most sites. Soil often covered these species on cut slopes because frost action or wetting and drying caused the soil to move (fig. 1). Partial or complete burial of plants coupled with plant characteristics such as small size, lateral growth habits, and slow growth rates appear to be the principal reasons for low survival of these species. The higher survival rates observed on fill slopes, where there was less evidence of soil movement than on cut slopes, support this conclusion.

Although elevation appeared to have little influence on average survival of all species, bitterbrush survival did appear to be affected by elevation of planting site. On fill slopes where survival is not complicated by soil movement, survival declined progressively from 50 to 36 to

Table 1--*Percent of survival 2 years after planting of bare-root shrubs on road cut and fill slopes, Entiat District of the Wenatchee National Forest*

Variable				Oregongrape	Bush penstemon	Squaw carpet ceanothus	Snowbrush ceanothus	Sedgeleaf buckbrush	Redstem ceanothus	Serviceberry	Bitterbrush	Blue elderberry	Snowberry
Site	Elevation	Aspect	Type of slope										
	Meters												
1	755	SE	Fill	--	45	--	25	30	37	--	50	62	--
2	792	SE	Cut	4	58	0	4	2	40	50	0	77	73
3	792	SE	Cut	9	47	33	24	--	--	58	13	87	--
4	914	SE	Cut	40	71	20	37	--	--	71	9	76	--
5	945	SE	Cut	0	20	0	7	--	--	60	0	67	--
6	1 098	E	Cut	3	46	6	20	--	--	22	11	80	--
7	1 098	E	Fill	60	86	48	74	--	--	86	36	78	--
8	1 158	W	Cut	7	49	11	42	--	--	80	9	77	--
9	1 216	SE	Cut	29	40	23	26	--	--	69	17	70	--
10	1 251	SE	Cut	27	53	20	27	--	--	40	13	--	--
11	1 463	W	Cut	13	37	10	23	--	--	77	0	--	--
12	1 478	S	Fill	54	80	37	74	--	--	88	3	--	--
Average survival[1/]				22	53	19	32	16	38	64	13	75	73

[1/] Average survival of all species on all sites was 38.

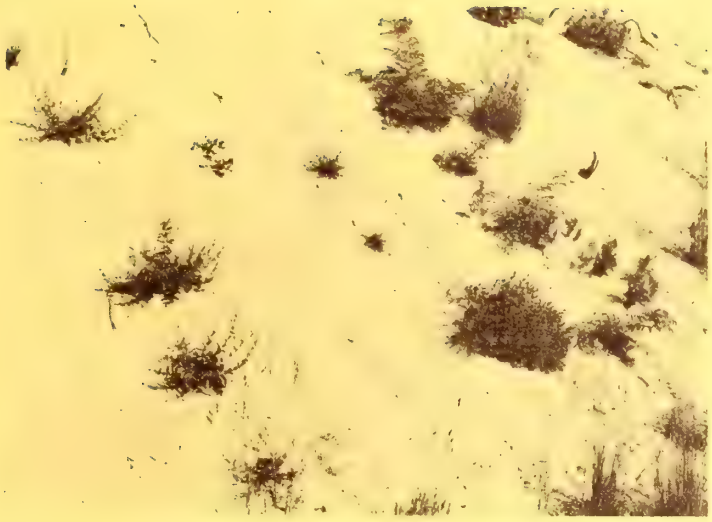

Figure 1.--Planted shrubs on a ravelling pumice cut slope of the Entiat Experimental Forest.

3 percent as elevation increased from 755 to 1 098 and to 1 478 m, respectively. This response to elevation by bitterbrush could be expected since it is a component of the ponderosa pine (*Pinus ponderosa* Dougl.)/bitterbrush/bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. & Sm.) habitat type generally found below 900 m in the Entiat Valley. Thus, seven of the planting locations were above the normal elevational range for bitterbrush. Also, the vigor and growth rate of both blue elderberry and serviceberry appeared to decline above 1 200 m. This response may result from either a shortened growing season because plants are covered by snow for a longer period or because we exceeded the elevational tolerances of these species.

For species with good survival rates but only planted on one or two sites, more plantings are needed before use can be recommended. Survival of snowberry on the one site planted was 73 percent and of redstem ceanothus 37 and 40 percent on the two sites planted.

OKANOGAN AND COLVILLE NATIONAL FOREST SITES

Average survival of all shrubs in the Okanogan and Colville National Forest plantings were 37 and 53 percent, respectively (tables 2 and 3). However, survival data from these evaluations must be interpreted with caution--the number of species planted at each location and the number of plantings of each species vary considerably.

Wild rose was planted at 14 locations on the two Forests and had one of the best survival rates of the species tested. There appeared to be little effect from elevation although the lowest survival was observed on two plantings at lower elevations on the Colville. Vigor of wild rose at most sites was fair to poor. Lower leaves on many plants appeared chlorotic, possibly indicating a higher nutrient requirement than some of the other shrub species.

Curl-leaf mountain mahogany was planted only on three midelevation sites on the two Forests. Average survival was about 42 percent, and vigor was good.

Table 2--*Percent of survival of bare-root shrubs planted on road cut slopes of the Colville National Forest*

Variable			Serviceberry	Bitterbrush	Wild rose	Curl-leaf mountain mahogany	Snowberry	Smooth sumac
Site	Elevation	Aspect						
	Meters							
1	853	N	--	--	22	--	80	--
2	853	SE	--	--	2/80	--	--	--
3	884	SW	--	--	2/50	--	22	--
4	914	S	--	50	--	40	--	--
5	914	S	--	2/--	10	--	0	--
6	914	SE	--	2/50	2/--	--	--	--
7	945	SE	--	--	2/90	--	--	--
8	975	E	85	--	--	40	--	52
9	1 005	SE	85	--	85	--	--	--
Average survival 1/			85	50	56	40	34	52

1/ Average survival of all species on all sites was 53.

2/ Estimated by individual responsible for plantings.

Table 3--*Percent of survival of bare-root shrubs planted on road cut slopes of the Okanogan National Forest*

Variable			Oregongrape	Bush penstemon	Snowbrush ceanothus	Bitterbrush	Wild rose	Curl-leaf mountain mahogany	Chokecherry	Kinnikinnick
Site	Elevation	Aspect								
	Meters									
1	853	S	22	62	--	67	54	--	42	--
2	975	NW	--	--	--	--	71	--	--	--
3	1 036	SE	2/--	--	--	2/--	2/70	--	--	--
4	1 127	SE	2/15	2/--	--	2/35	2/30	2/--	--	--
5	1 158	SE	14	2/50	--	0	2/50	2/45	--	0
6	1 310	S	--	0	0	0	--	--	--	--
7	1 341	W	--	2/--	--	31	2/70	--	2/--	--
8	1 371	S	--	2/40	0	--	2/80	--	2/35	--
9	1 463	S	45	--	34	--	85	--	--	--
Average survival 1/			24	38	11	27	63	45	39	0

1/ Average survival of all species on all sites was 37.

2/ Estimated by individual responsible for plantings.

Some of all the remaining six species planted on the Okanogan National Forest survived except the one planting of kinnikinnick (table 3). Bush penstemon survival was 40 percent or greater on three of the four sites where it was planted. However, on the fourth site (site 6), no shrubs of any species survived, indicating there may be other reasons for mortality at this particular location than a low inherent survival potential of the plants. The vigor of the surviving bush penstemon was generally fair to good. Bitterbrush survival on the Okanogan National Forest was high at the lowest elevation site (67 percent), and vigor was good. At sites above 1 127 m, survival was poor and vigor of plants fair. Survival of snowbrush ceanothus and Oregongrape varied but was generally poor, and vigor was fair to poor on all sites. Chokecherry survival was 35 and 42 percent, but vigor of plants was only fair.

Serviceberry, bitterbrush, snowberry, and smooth sumac showed some survival in the Colville trials (table 2). The elevational range of these plantings was too narrow to enable us to evaluate survival differences in response to elevation. Serviceberry survival was 85 percent on both sites planted. However, most plants were small and appeared to be growing very slowly. Vigor was rated only fair. Smooth sumac was planted at only one location and bitterbrush at two, but survival and vigor of both species were good. Snowberry appears to be sensitive to aspect--survival varied from 0 to 22 percent on southerly aspects compared with 80 percent on a north aspect. Vigor of surviving plants was poor.

In the range between 850 and 1 200 m, elevation generally appeared to have minimum influence on the species tested. Below this range, species such as bitterbrush would most likely be more suitable. Above 1 200 m some species not tested in our trials such as willows (*Salix* sp.) and Sitka alder (*Alnus sinuata* (Reg.) Rydb.) may exhibit greater survival.

Seedling size is very important. The stem portion must be tall enough to withstand inundation by ravelling, loose, soil material; but the root system must be small enough to allow hand planting with minimum site disturbance. Use of containerized seedlings may overcome the planting difficulty encountered when large field-grown seedlings are used.

Another possible factor affecting our shrub seedling survival was wildlife. South-facing road cuts are some of the first sites to be free of snow in the spring. Small young shrubs are very attractive to browsing animals. We observed a striking loss of snowbrush ceanothus seedlings to deer during the first spring after planting on the Wenatchee National Forest.

RECOMMENDATIONS

Despite an obvious need for additional testing, several species evaluated in this study can be recommended for operational use. Blue elderberry and bush penstemon appear suited to a wide variety of sites. Vigor of wild rose and serviceberry was not as good as blue elderberry and bush penstemon, but both species exhibited good survival on most sites tested. Supplementary fertilization may enhance the effectiveness of these two species. Bitterbrush can be recommended for use on sites at lower elevations--probably below 1 100 m. On sites with severe soil ravelling or road cut slopes, plantings of squaw carpet ceanothus and snowbrush ceanothus should probably be restricted to fill slopes. Oregongrape, although a common plant in eastern Washington, was

unsatisfactory in these trials. Most of the other species examined were not tested on enough sites to indicate their suitability for operational use.

In future operational plantings, we suggest careful recordkeeping of planting procedures and locations for subsequent use in evaluating species performance. Information from such plantings will aid the nurseryman and land manager in determining which species (and geographic sources of each) will have the best chance of survival at particular locations.

A seed source close to the intended area of planting (for seedling production by the nursery) is also likely to improve revegetation success. Thus, the development of an effective, operational shrub planting program is a long-term effort.

Care of bare-root planting stock is also a critical factor in survival. Only dormant plants should be planted. Planting crews should take to the field only the number of plants that can be planted in 1 day. Excess stock should be returned to cold storage and planted first the next day. Seedlings should be planted only in moist soil, never under droughty conditions.

Considerable research is needed to develop sufficient information for complete shrub planting prescriptions on severely disturbed lands in the interior Pacific Northwest. Immediate research should emphasize: characterization of growth form, growth rate, and physiological requirements and tolerances of shrubs; relation of plant requirements to soil and site factors found on severely disturbed sites; increased knowledge of the effect of fertilizers on survival and growth in nursery and field plantings; determination of best planting season; and effect of physical controls such as contour trenching on survival and growth of shrubs.

From our limited experience, we predict shrub plantings will be a useful practice along with other soil conservation measures to help the land manager protect wildland soil and water resources in the interior Pacific Northwest.

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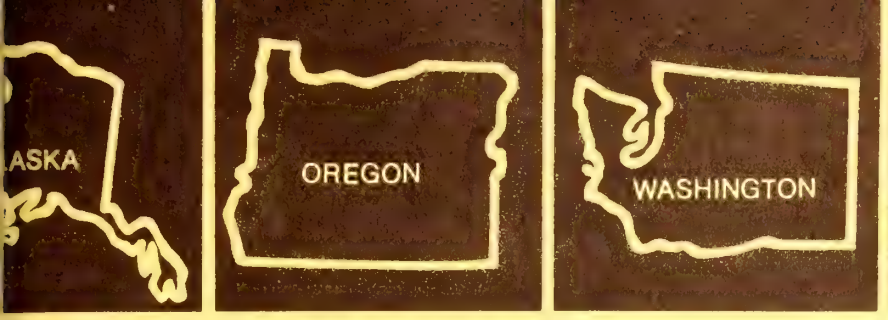

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

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DISPERSED RECREATION ON THREE FOREST ROAD SYSTEMS IN WASHINGTON AND OREGON: FIRST YEAR DATA [1/]

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ABSTRACT

Data produced during the 1st year of a 3-year study of dispersed road recreation along forest roads in Washington and Oregon are described in this report. Dispersed road recreation includes both overnight camping at dispersed undeveloped sites and day activities which take place along and adjacent to forest roads.

A Code-A-Site inventory identified 622 camper-established sites on 319 miles of road in the three study areas, most of them located near water. Dispersed use of the three study areas was concentrated on weekends and holidays. In one of the areas, 40 percent of the use was during elk season. Observations of 1,613 dispersed recreation parties, and conversations with 630 of them, indicated that 91 percent had previously visited the areas and 85 percent lived within 100 miles.

KEYWORDS: Recreation (dispersed road).

[1/] Originally presented to the Multiagency Workshop, "New Perspectives on Recreation Resource Management," March 8-12, 1976, Bend, Oregon.

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Dispersed road recreation, defined as day activities and camping at informal, undeveloped sites (generally user established) along forest roads, appears to be increasing on National Forests, other roaded multiple use public lands and private forest lands open to public entry. Dispersed road recreation differs from use at developed campgrounds and recreation areas in that no official facilities are provided. Dispersed road recreation also differs from dispersed roadless recreation in adjacent Wilderness or back country because the activity occurs along forest roads accessible by passenger vehicles.

Dispersed road recreation, defined as day-use activities and camping at informal sites along forest roads, is increasingly evident in many multiple use areas.

The National Forest System contains nearly 25,000 miles of hard surface forest highways and more than 200,000 miles of gravel and dirt forest roads along which dispersed recreation can take place. Data on use of these National Forest opportunities are sketchy, in part because of the dispersed nature of the activity and its occurrence at unofficial, user established sites. Recent estimates indicate, however, that driving for pleasure on these roads totals 45 million visitor days annually with possibly another 60-80 million visitor days spent in other dispersed activities in roaded areas such as hunting, fishing, and berrypicking (USDA Forest Service 1976a). The importance of these uses is emphasized in the recently recommended program direction for the Forest Service prepared under the Forest and Rangeland Renewable Resources Planning Act of 1974.

There are frequently signs of dispersed recreation at a variety of road locations, such as forest openings along streams or lakes, or where it is possible to get off forest roads to a pleasant grove of trees or viewpoint. A wide variety of activities are involved. Fishermen, berrypickers,

campers, firewood cutters, hikers, hunters, motorbike riders, picnickers and off-road vehicle users are among the recreationists that enjoy these settings. The growing use of dispersed settings is probably related to such factors as: the increased numbers of motorhomes, pickup campers, and trailers; more four-wheel drive vehicles and motorbikes that make low-standard roads more usable; extensions of logging roads to more forest lands; higher motor fuel costs that make short trips to a nearby forest more attractive than long-distance vacations; and the crowded and regimented situations prevailing at many developed campgrounds, where camping fees up to $5 or more per night are charged.

There is little published information about dispersed road recreation. A report by Lloyd and Fisher (1972) indicated that dispersed recreation at unimproved locations (including that on roaded, multiple use lands as well as in roadless areas) accounted for more use and was growing faster on the National Forests than was concentrated use at developed sites. But, except for a 1-day study near Perth, Australia (Spriggins 1975), we have found no specific studies of dispersed recreation on forest roads. There are reports on methods useful for measuring dispersed use--on roads as well as roadless areas (James and Schreuder 1972, James and Henley 1968) and many studies of dispersed wilderness recreation. One recreation textbook discusses "extensive" (dispersed) forest recreation use and its relationship to resource management (Douglas 1969). There is a growing literature on recreation activities that take place in dispersed road recreation areas, including hunting, fishing, snowmobiling, and off-road vehicle use. In British Columbia several travel guides have been published on logging road travel (Merriman and Merriman 1973a, 1973b; Bernsohn and Bernsohn 1976).

FOREST SERVICE STUDIES OF DISPERSED ROAD RECREATION IN THE PACIFIC NORTHWEST

During 1973-74, the topic of dispersed road recreation emerged in discussion between forest managers and researchers in the Pacific Northwest as a high priority for study. Increased dispersed camping was reported on many forest roads throughout the region and forest managers needed research-based information about the nature and extent of this use, the impacts it created, and the recreation values it involved. The Forest Service Recreation Research Project in Seattle carried out pilot studies of dispersed road recreation during 1974 on five forest road systems on the Mt. Baker-Snoqualmie and Deschutes National Forests in Washington and Oregon. The purpose of these pilot studies was to gather preliminary information for proposing and planning a subsequent major study of dispersed road recreation.

Pilot Study 1974

Five forest road systems were included in a 1974 pilot study. They were selected to represent a range of conditions under which dispersed recreation reportedly occurred. One of the first things observed on these roads was the presence of many dispersed, informal campsites that had been established by users. These dispersed sites appeared to be an important focal point for camping and day activities along forest roads, but there was no systematic information about their characteristics or use as they were not included in any data system. What was needed was a method of inventorying the sites systematically as to their location, characteristics, and

recreation-caused impacts--data that might be important from a resource protection or recreation use standpoint. Thus, much of the pilot study efforts were devoted to developing and testing Code-A-Site: A System for Inventory of Dispersed Recreational Sites in Roaded Areas, Back Country and Wilderness (Hendee et al. 1976). Code-A-Site uses edge-punch cards and needle-sort methods (or computer if desired) to record, store, retrieve, and summarize basic data about dispersed road sites. Code-A-Site was also adapted for and tested in Wilderness and back country because of the similar, dispersed nature of campsites in those roadless locations.

The Code-A-Site inventory of the five forest road systems in the 1974 pilot study identified 368 informal sites established by users on 249 miles of forest road.[2/] Heavy use was observed at many sites on weekends and holidays by campers and day users who pursued a full range of activities. Based on the pilot study results, a cooperative 3-year study of dispersed road recreation was proposed, funded, and initiated during 1975 in cooperation with National Forest managers.

Three-Year Study 1975-77

The dispersed road recreation study is being conducted in three "case-study" areas in Washington and Oregon. During 1975, Code-A-Site inventories of all dispersed sites were completed on the forest roads in each area; the amount of dispersed camping and day use was determined; and characteristics of use and users were described from observation and conversational data. This paper describes the data collected during the 1975 field season.

A user survey is underway in 1976 to collect detailed information on the characteristics, participation patterns, preferences, and management-related attitudes of dispersed users. In 1977 the study will focus on important issues identified in the previous years of research. Ultimately, data from all three years will be synthesized in the form of planning and management guidelines for dispersed road recreation on the kind of areas studied.

THREE CASE-STUDY AREAS

Three case-study areas were selected by researchers and Forest Service managers to reflect a range of dispersed road recreation opportunities in the Washington-Oregon region. Ten criteria were to be represented among the areas including: (1) interest by local managers in participating in the study, (2) intermingled public and private land ownership, (3) current or imminent road closures to public traffic because of perceived problems, (4) a spectrum of nearby recreation opportunities including roadless areas and developed campgrounds, (5) proximity to large metropolitan areas such as Portland and Seattle for two of the areas, (6) off-road vehicle activity, (7) forest conditions typical of large categories of National Forest land,

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[2/] The pilot study data are summarized in two unpublished reports: Mack L. Hogans (1974), "Public Use of Forest Roads Pilot Study--Summer 1974. Snoqualmie National Forest, White River and Bend Ranger Districts." Unpublished summary report, 42 p., mimeogr.; and Dan Wood (1974), "Public Use of Forest Roads Pilot Study, 1974. Deschutes National Forest, Bend and Sisters Ranger Districts." Unpublished summary report, 21 p., mimeogr.

(8) current use of a range of different timber-harvesting methods, (9) fairly closed transportation systems to facilitate measuring traffic, and (10) a minimum of unusual recreation attractions that might distort study findings.

National Forest managers in Washington and Oregon were invited to submit areas meeting most of the criteria that they would like considered for inclusion in the study. A total of 28 candidate areas were submitted from which the following three areas were selected (fig. 1).

Figure 1.--Location of the Greenwater, Taneum-Manastash, and Upper-Clackamas study areas.

Greenwater Study Area

The Greenwater drainage is 60 miles southeast of Seattle on the White River Ranger District of the Mt. Baker-Snoqualmie National Forest. The main Greenwater road leaves Highway 12, a scenic cross mountain route to eastern Washington, less than 20 miles from a main entrance to Mt. Rainier National Park. There are no developed campgrounds in the study area but there are private, State, and Forest Service campgrounds within 20 miles.

In much of the area, alternative sections of land are owned by Weyerhaeuser Co. The road system has been largely constructed for timber harvest purposes and is maintained under share cost road maintenance agreements between the Forest Service and Weyerhaeuser. Douglas-fir is the major timber type; and many large clearcuts are found throughout the drainage, although shelterwood and selective salvage cuts have also been used. Active logging is in progress at several locations, and additional timber harvest and road construction are planned.

The Greenwater drainage contains 78 miles of gravel and dirt logging roads; but fire closures during 1975 reduced the road available to dispersed recreationists to 23 miles, most of which is located along the Greenwater River. The roads in the drainage provide access to several trails leading to the Pacific Crest National Scenic Trail at the head of the drainage or other back country locations.

Taneum-Manastash Study Area

The Taneum-Manastash area is on the Ellensburg Ranger District of the Wenatchee National Forest on the east side of the Cascade Mountains. The study area lies a few miles south of Interstate 90, approximately 20 miles west of Ellensburg and 6 miles south of Cle Elum, Wash. The area boundary is a 2-hour drive from Seattle. Adjacent and intermingled lands are owned by the Washington Department of Natural Resources and Burlington Northern Railroad. The L. T. Murray State Game Range also adjoins the area.

The area includes 6 miles of blacktop road along Taneum Creek, 47 miles of mainline logging road, and 44 miles of dirt spur roads. The study area covers approximately 70,000 acres and ranges in elevation from 2,000 feet along Taneum Creek to the 6,300-foot top of Quartz Mountain. There are several trailheads leading to adjacent back country and four nearby lakes. Public use in the summer includes motorbike riding, camping, fishing, and horseback riding. In the fall, the area is heavily used by deer and elk hunters. The minimally developed Taneum Creek campground, just inside the area, has 21 sites. There are also two official, minimally developed campsites at Tamarack Springs, four at South Fork of Taneum Creek Meadows, five at Keenan Meadows trailhead, and three at Quartz Springs.

The main timber species include Douglas-fir, ponderosa pine, western larch, and true fir. Local silvicultural practices include clearcutting and some selective harvest. The area has several large meadows and a long history of sheep and cattle grazing including some currently active cattle grazing allotments.

Upper-Clackamas Study Area

The Upper-Clackamas study area is on the Clackamas and Estacada Ranger Districts of the Mt. Hood National Forest. The area lies adjacent to the main Clackamas River road, a blacktop, two-lane forest highway that serves as a scenic forest loop highway from Portland through the Mt. Hood and Willamette National Forests to the town of Detroit.

The Clackamas drainage has hundreds of miles of forest roads built primarily for timber harvest, three minimally developed and three highly developed Forest Service campgrounds, and one developed picnic site in Austin Hot Springs owned by Portland General Electric Co. Popular activities in the area include fishing, rafting, and swimming in the Clackamas River and berry-picking, firewood cutting, and picnicking along the forest roads.

Since the Clackamas drainage is such a large area, only four of its roads were selected: 21 miles of the Clackamas highway from Ripplebrook to Squirrel Creek, the Fish Creek road system totaling 80 miles, 70 miles of the Oak Grove-Shellrock Creek road system, and 30 miles of the Squirrel Creek road system.

METHODS AND FINDINGS

The following descriptions of findings from the first year (1975) of the dispersed road recreation study pertain to (1) dispersed sites and their characteristics, (2) amount and patterns of dispersed use, and (3) characteristics of use and users based on observation and conversational data. The research methods used to compile the data on these three topics are described at the beginning of each section.

It should be emphasized that the findings described are limited to the case study areas described and cannot be generalized to all dispersed road recreation areas.

Dispersed Recreation Sites

Code-A-Site inventories identified a total of 622 dispersed sites on the 319 miles of road in the three case-study areas. Details of the procedures appear in a publication describing Code-A-Site (Hendee et al. 1976). A site was defined as a specific location showing evidence of recreation use, which almost always includes a fire circle and other impacts or signs of camping or recreation activity. Most of these sites (83 percent) could accommodate parties with more than one camping vehicle or tent--multiple unit sites (table 2, item 2). However, 69 percent of the parties we observed had only one tent or vehicle (table 4, item 4).

The location and characteristics of established sites provide "trace" evidence of the dispersed recreation behavior that has occurred. Together, they give a profile of the dispersed camping opportunities. They reflect behavior of recreationists in creating and using the sites and the interaction of recreation with other resource uses in taking advantage of the effects of timber harvest and road construction that created potential sites.

A. SITE LOCATION AND DENSITY

Table 1 indicates the distribution and density of sites on the river bottom, midslope, and ridgetop roads in the three areas. The density of established sites varied sharply with road location. Sites were most concentrated (about four to nine sites per mile) on river bottom roads in all three areas. Sites on midslope roads were generally located at stream crossings. Some ridgetop roads featured sites at vantage points.

The concentrated distribution of sites along the river bottoms underscores the importance of water as a dispersed recreation attraction. Eighty-four percent of all sites were located directly adjacent to or within a few hundred feet of water (table 2, item 6). The concentration of sites on river bottom roads may also reflect a tendency for central location on main roads leading into each area since even on river bottom roads the density of established sites was reduced at the more distant and less accessible locations.

Table 1.--Distribution of dispersed sites and site density on river bottom, midslope roads, and ridgetop roads in the three study areas

Road location	GREENWATER			TANEUM-MANASTASH			UPPER CLACKAMAS			TOTAL--THREE AREAS		
	Miles of road	No. of sites	Average density si./mi.	Miles of road	No. of sites	Average density si./mi.	Miles of road	No. of sites	Average density si./mi.	Miles of road	No. of sites	Average density si./mi.
River bottom roads	9	64	7.1	10	96	9.6	48	179	3.7	67	340	5.1
Midslope roads	5	23	4.6	10	57	5.7	32	25	.8	47	105	2.2
Ridgetop & side roads	9	30	3.3	75	138	1.8	121	10	.1	205	177	1.9
Total/Average:	23	117	5.1	95	291	3.1	201	214	1.1	319	622	1.9

Greenwater primarily includes river bottom road which accounts for its having the highest average site density of 5.1 sites per mile of road. Fire closures and active logging during 1975 closed 45 additional miles of road containing about 20 sites in the Greenwater which would have lowered the average site density for the area to about two sites per mile, a figure comparable to the other areas.

B. SITE CHARACTERISTICS

Table 2 summarizes Code-A-Site data on 11 dispersed site variables. Other site variables available in the Code-A-Site inventory but not reported here include ground cover, crown cover, exposure, elevation, and availability of forage for recreation stock use.

The site characteristics described in table 2 are summarized in the following:

1. Site Location:

On the average about equal numbers of sites were located on main and spur roads--the most common requirement seemed to be accessibility to passenger cars. In Greenwater and Taneum more than half the sites were on spur roads, but in the Clackamas most were located on main roads.

2. Site Capacity:

Most sites are spacious in that they can accommodate several tents or recreation vehicles. Clackamas was the only area where a majority of the sites could not accommodate three or more vehicles. Taneum had the largest site capacity, apparently due to its more open, east-side forest setting. Nearly three-fourths of the sites in the Taneum area could accommodate four or more vehicles.

3. Visual Isolation:

Most sites featured some visual isolation from other campsites. Nearly 90 percent of all sites had only one to three other sites in view and 43 percent had no other sites in view. In the more crowded Greenwater area, however, only 35 percent of the sites had total visual isolation from other sites. Because of the low occupancy rates (table 2, item 11) the degree of

Table 2.--Dispersed recreation site characteristics in three roaded areas in the Pacific Northwest based on a 1975 Code-A-Site inventory [1/]

Characteristics	Greenwater		Taneum-Manastash		Upper Clackamas		Total	
	No.	Percent	No.	Percent	No.	Percent	No.	Percent
1. Sites by road location:								
Main road	49	(42)	79	(27)	123	(58)	251	(40)
Spur road	65	(55)	153	(52)	25	(12)	243	(39)
Informal road	3	(3)	41	(14)	62	(29)	106	(17)
4-wheel drive road	--	--	20	(7)	3	(1)	23	(4)
2. Site capacity:								
No vehicles, tent only	2	(2)	10	(3)	14	(7)	26	(4)
1 vehicle	12	(10)	8	(3)	58	(27)	78	(13)
2 vehicles	37	(32)	16	(6)	101	(47)	154	(25)
3 vehicles	20	(17)	47	(16)	17	(8)	84	(13)
4 and greater vehicles	46	(39)	212	(72)	24	(11)	282	(45)
3. Visual isolation, No. of other sites in view:								
0	41	(35)	128	(44)	96	(46)	265	(43)
1-3	66	(56)	137	(47)	88	(42)	291	(47)
4-5	9	(8)	23	(8)	18	(9)	50	(8)
6 and greater	1	(1)	3	(1)	7	(3)	11	(2)
4. Dispersal: No. of sites within 1/2 mile:								
0	4	(4)	7	(2)	24	(11)	35	(6)
1-3	43	(38)	108	(37)	26	(12)	177	(29)
4-5	14	(13)	44	(15)	42	(20)	100	(16)
6 and greater	51	(45)	132	(46)	120	(57)	303	(49)
5. Firewood availability:								
Abundant	12	(10)	27	(9)	52	(24)	91	(15)
Available	104	(89)	220	(75)	116	(55)	440	(70)
Scarce	0	(0)	45	(15)	40	(19)	85	(14)
None	1	--	1	--	5	(2)	7	(1)
6. Water availability:								
Adjacent to site	53	(45)	111	(38)	149	(70)	313	(50)
Available nearby	22	(19)	170	(58)	18	(8)	210	(34)
No water available	42	(36)	12	(4)	47	(22)	101	(16)
7. Toilets:								
Accessible to site	0	(0)	76	(35)	6	(3)	82	(13)
Not accessible to site	117	(100)	217	(65)	208	(97)	542	(87)
8. Facilities at site:								
None	155	(98)	207	(75)	211	(98)	533	(89)
Sign	2	(2)	49	(18)	0	(0)	51	(9)
Garbage can	0	(0)	2	--	2	--	4	--
Table	0	(0)	11	(4)	1	--	12	(2)
9. Estimated environmental impact:								
Extreme	2	(2)	0	(0)	8	(4)	10	(2)
Heavy	11	(9)	47	(16)	13	(6)	71	(11)
Moderate	36	(31)	146	(50)	76	(35)	258	(41)
Light	68	(58)	100	(34)	117	(55)	285	(46)
10. Estimated frequency of site use:								
Heavy	7	(6)	0	(0)	10	(5)	17	(3)
Frequent	26	(22)	35	(12)	14	(6)	75	(12)
Moderate	18	(15)	62	(21)	40	(19)	120	(19)
Slight	16	(14)	99	(34)	53	(25)	168	(27)
Infrequent	50	(43)	97	(33)	96	(45)	243	(39)
11. Recorded frequency of use:								
Heavy (25-56 nights)	2	(2)	13	(4)	9	(4)	24	(4)
Frequent (19-24 nights)	1	--	10	(3)	9	(4)	20	(3)
Moderate (13-18 nights)	7	(6)	22	(8)	23	(11)	52	(8)
Slight (7-12 nights)	22	(19)	42	(14)	40	(19)	104	(17)
Infrequent (1-6 nights)	24	(21)	88	(30)	73	(34)	185	(29)
Unused	61	(52)	121	(41)	60	(28)	242	(39)

[1/] All totals for study area subsections add to approximately 117 for Greenwater, 293 for Taneum-Manastash, and 214 for the Upper Clackamas. Totals have been omitted to save space. All percentages add to 100 down the page with the exception of number 8, Facilities at site, which does not have mutually exclusive categories.

isolation afforded users of these sites is greater than implied by the visual proximity to other sites.

4. Dispersal:

Despite visual isolation, most sites were not dispersed evenly throughout each area but were concentrated along popular stretches of road. More than half of the sites in Greenwater and Taneum, and nearly half in Clackamas, were located within 1/2 mile of at least four other sites.

5. Firewood Availability:

Firewood is definitely not the problem for campers in dispersed areas that it is in most developed campgrounds. Firewood, either natural or from logging slash, was available at almost all sites.

6. Water Availability:

The affinity of dispersed recreationists for water was evident in the location of 84 percent of all sites directly adjacent to or nearby a river or stream. Taneum, where there were less river bottom roads and fewer streams, had many sites established adjacent to meadows. In that area, water serving many sites was found in springs rather than rivers and year-round streams.

7. Toilet Accessibility:

No sites in the Greenwater were accessible to a toilet, and only six in Clackamas, but 76 sites (25 percent) in Taneum were within usable reach of an outhouse toilet or makeshift latrine, many of them apparently constructed by users at sites attracting extended stays by hunters.

8. Facilities:

There is a small scattering of facilities among the sites, mostly fire-prevention signs, some garbage cans put out by forest managers, and a few tables constructed by campers.

9. Environmental Impacts:

Field judgments of the category of environmental impact from use indicated that from 10 to 17 percent of the sites were extremely or heavily impacted, and most were judged moderately or lightly impacted. The sites that were judged extremely or heavily impacted appeared to be among the most popular with users. The impact did not seem to deter people from using them.

10. Estimated Use:

During the Code-A-Site inventory an estimate of the frequency of use was made for each site based on impacts and other evidence of recreation activity (table 2, item 10). These field estimates implied that a large proportion of sites were used very infrequently and that a minority of the sites accommodated most of the dispersed recreation use. There was a strong relationship (Gamma .58) between these estimated frequency categories of use and

categories of observed use which demonstrates the "ballpark" accuracy of these field estimates.

11. Observed Use:

During the 1975 summer, the actual occupancy of each dispersed site was recorded by patrolmen (table 2, item 11). These measured data indicated the same pattern as the estimated frequency of use--a few sites sustain most of the use in all the areas. Thirty-nine percent of the sites were not used at all during the summer and 29 percent were used only 1 to 6 nights.

AMOUNT AND PATTERNS OF DISPERSED USE

A check station provided a complete tabulation of day use in the Greenwater, while estimates of the amount of dispersed day use in the Taneum and Upper-Clackamas areas were derived from mechanical traffic counter data, calibrated by observations during sample weekdays, weekends, and holiday weekends. Because of a large expected sampling error from the procedures used and to establish a baseline of use over time, use will be sampled again during the second year of the study. In all three areas overnight use was determined from daily counts by patrolmen.

The accuracy of use estimates varied between areas. The Greenwater check station provided the most accurate use data as recreation entry was directly observed. Table 3 shows the amount of dispersed day and overnight use in the three areas during weekdays, weekends, and holiday weekends (July 4 and Labor Day), and for deer and elk seasons in the Taneum area. Figure 2 shows the distribution of use from day to day in the Greenwater area. In the Clackamas, use estimates were compiled from three sources: Electronic traffic counter data recorded by field assistants, a special traffic count study by the Forest, and official Recreation Information System (RIM) samples being used for developing national use estimates. In the Taneum, use estimates were weakest because they were based on pneumatic hose traffic counter data calibrated by only 6 sample days. Taneum has the most complicated use patterns with three major entry points and a complicated network of interior roads. A special effort will be made to improve use estimates in this area the second year of the study.

A. PEAK USE AND DAY USE

The three study areas attracted 111,484 man-days of use. This figure understates total dispersed use because it is restricted to July 3 through Labor Day and excludes hunting season, except for Taneum. Our casual observation suggests that considerable spring and fall weekend camping and day use occurs depending on weather. Some winter use also occurs.

Data in table 3 and figure 2 indicate that both dispersed day use and camping are peak use phenomena on weekends and holiday weekends in these areas since low levels occur during weekdays. Use during weekends and holidays constituted a majority of the total summer use except in Taneum where hunting seasons accounted for a majority of the use. The wide fluctuation in weekend and weekday use is especially apparent in figure 2 which shows daily use for the Greenwater area.

Table 3.--Amount of dispersed road recreation use in the Greenwater, Taneum-Manastash, and Clackamas area drainages--Summer/Fall 1975.

Use	Day use			Overnight			Total		
	Number	Aver./ day	Percent	Number	Aver./ day	Percent	Number	Aver./ day	Percent
	Man-Days--Any Portion of 24-Hour Period--12 Noon to 12 Noon								
GREENWATER DRAINAGE, MT. BAKER-SNOQUALMIE NATIONAL FOREST, WASHINGTON									
[1/] 36 weekdays (Mon-Th)	2,088	58	(69)	936	26	(31)	3,024	84	(27)
21 weekend days (Fri, Sat, Sun)	4,263	203	(69)	1,932	92	(31)	6,195	295	(55)
6 holiday weekend days	1,522	253	(74)	532	155	(26)	2,054	342	(18)
TOTAL--63 DAYS	7,873		(70)	3,400		(30)	11,273		(100)
TANEUM-MANASTASH DRAINAGE, WENATCHEE NATIONAL FOREST, WASHINGTON									
[2/] 36 weekdays (Mon-Th)	4,068	113	(72)	1,584	44	(28)	5,622	156	(11)
21 weekend days (Fri, Sat, Sun)	5,859	279	(61)	3,822	182	(39)	9,681	461	(20)
7 holiday weekend days	2,856	408	(48)	3,150	450	(52)	6,006	858	(12)
21 deer days	4,851	231	(64)	2,730	130	(36)	7,581	361	(15)
14 elk days	11,225	802	(54)	9,414	672	(46)	20,639	1,474	(42)
TOTAL--99 DAYS	28,859		(58)	20,700		(42)	49,529		(100)
CLACKAMAS DRAINAGE, MT. HOOD NATIONAL FOREST, OREGON									
Clackamas highway (21 mi)									
36 weekdays (Mon-Th)	9,396	261	(77)	2,880	80	(23)	12,276	341	(38)
21 weekend days (Fri, Sat, Sun)	11,899	567	(82)	2,610	124	(18)	14,509	690	(45)
6 holiday weekend days	4,472	745	(93)	720	120	(14)	5,192	865	(17)
Subtotal	25,761		(81)	6,210		(19)	31,977		(100)
Fish Creek (80 mi)									
36 weekdays (Mon-Th)	5,724	159	(96)	216	6	(4)	5,940	165	(32)
21 weekend days (Fri, Sat, Sun)	7,420	353	(78)	2,100	100	(22)	9,520	453	(51)
6 holiday weekend days	2,965	494	(91)	280	46	(9)	3,245	540	(17)
Subtotal	16,109		(86)	2,596		(14)	18,705		(100)
Oak Grove-Shellrock Creek (70 mi)	Use Data Not Yet Available								
Squirrel Creek (30 mi)	Use Data Not Yet Available								
Total, two roads									
Weekday	15,120	420	(83)	3,096	86	(17)	18,216	506	(36)
Weekend	19,319	919	(80)	4,710	224	(20)	24,029	1,144	(47)
Holiday	7,437	1,240	(88)	1,000	166	(12)	8,437	1,406	(17)
TOTAL--63 DAYS	41,876		(83)	8,806		(17)	50,682		(100)

[1/] Based on check station count.

[2/] These use figures are based on mechanical traffic counts adjusted by sample observations and a calculated average of 4 persons per vehicle.

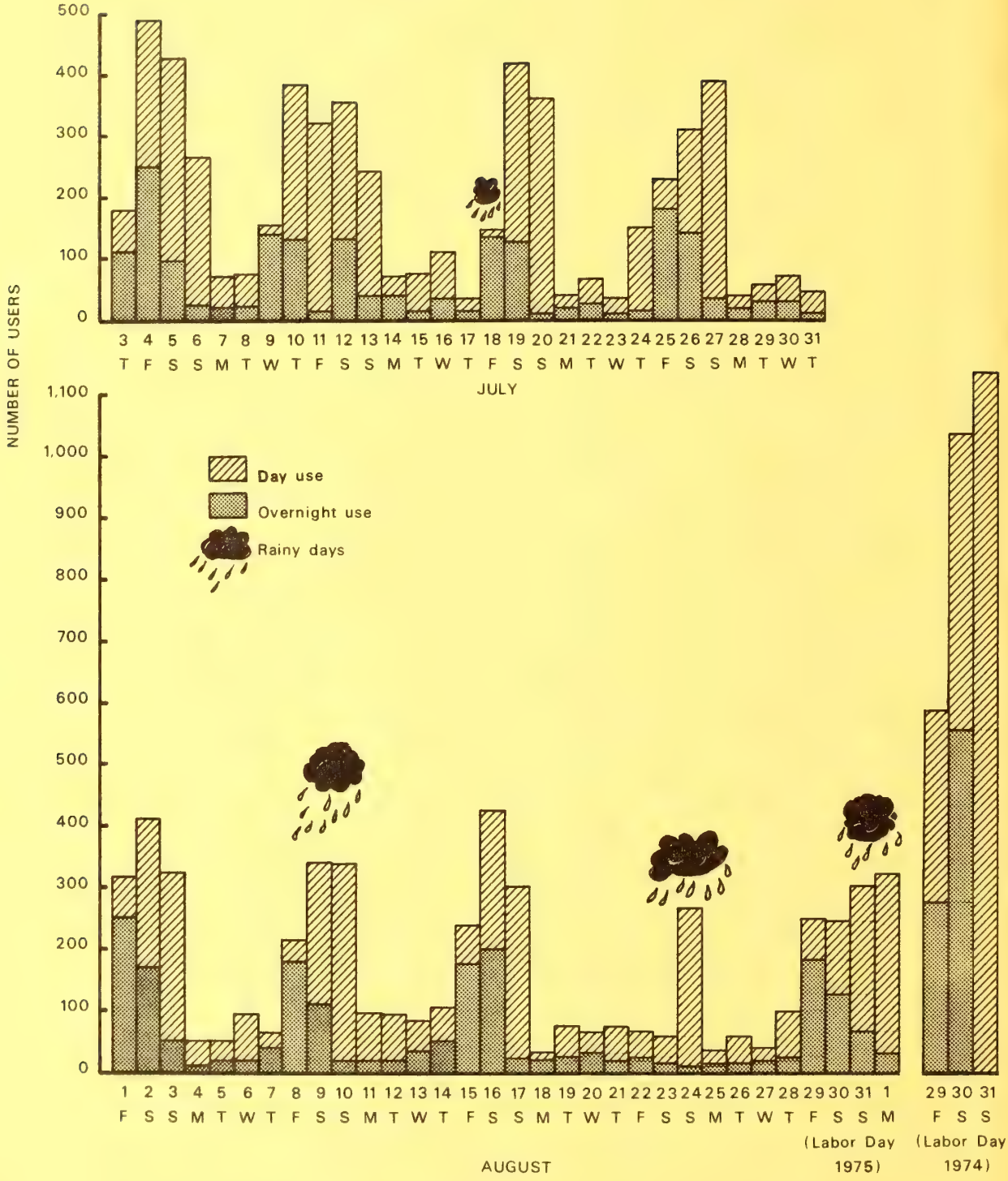

Figure 2.--Daily use in the Greenwater area, summer of 1975 and Labor Day weekend, 1974, based on total count.

Day use was more prevalent than camping in all three areas. Total day use (any portion of a day spent in the area) averaged 70 percent with Clackamas above average and Taneum below average. If data are aggregated in terms of number of visits--that is, visitors are counted only once when entering the area whether or not they stay more than 1 day--the balance is tipped even farther toward day use. The only location where overnight camping exceeded day use was during holidays in the more remote Taneum area (52 percent overnight use), and it approached half the use (46 percent) in that area during elk season.

We were quite surprised at the large proportion of day use since so much of our attention had previously been focused on dispersed sites that appeared to be predominately used for camping. Two kinds of day use were observed: (1) day users on 1-day outing from home and (2) day users who were camped in nearby dispersed areas or developed campgrounds. Information about the relative proportion of these groups is being collected during the summer of 1976 as part of the user survey. Driving for pleasure on forest roads in cars, pickups, jeeps, or motorbikes, berrypicking, fishing, hunting, firewood cutting, or hiking--in short, a whole range of recreation activities seemed to attract day users as well as campers.

A variety of activities seem to attract dispersed road recreationists including camping and relaxing.

We observed that dispersed use was very dependent on weather, in that daily use would rapidly fluctuate with weather conditions. Figure 2 shows daily use in the Greenwater area, including 6 rainy weekend days and Labor Day weekend. As figure 2 indicates, dispersed use is severely depressed during inclement weather. Use during the wet Labor Day weekend totaled 794 visitors in 1975 compared to 2,755 visitors during 1974 when it was warm and sunny.[3/] But even on rainy Fridays (such as July 18 and August 8) or Saturdays (August 23), dispersed use will apparently rebound if the sun shines the next day. This suggests a relationship between short-term dispersed road use and

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[3/] Table 2 shows no overnight recreation use for Sunday of Labor Day weekend 1974, nor any use for Labor Day (Monday 1, 1974). The Greenwater drainage was evacuated at about 3:30 p.m. on Sunday, August 31, 1974, when a forest fire swept the area.

weather conditions. We suspect that dispersed road recreation, with its high proportion of day use, is more spontaneous than developed campground or roadless area use and may fluctuate more rapidly in response to local weather conditions.

The amount of dispersed use during hunting season was impressive in the Taneum area, with average daily use 80 percent higher during elk season than even during holiday weekends. The Clackamas is not noted for good hunting and forest managers report minimal use during both deer and elk season. Greenwater has only fair deer hunting; but if a heavy snow drove elk from Mt. Rainier to the Greenwater winter range before mid-November, the area would certainly attract many elk hunters. This usually doesn't happen and didn't occur during 1975 when forest managers' reports and our periodic checks indicated few users in the area during deer or elk season.

The importance of elk hunting in the Taneum was underscored in conversations with several summer visitors who said they were there "to see how the elk were doing," and even during deer season, many hunters said they were "more interested in scouting out the elk situation than in bagging a deer." Sunday before the Monday opening of elk hunting, nearly 2,000 hunters crowded the area filling nearly all the 291 dispersed sites, many of which were used only during elk season.

CHARACTERISTICS OF USE AND USERS

During the 1975 summer, field assistants assigned to each area systematically patrolled the roads each Thursday through Monday. They wore Forest Service uniforms, drove government cars (except that a trailbike was often uses in the Taneum area), and contacted users at all occupied sites in the same manner as other Forest Service recreation or fire patrolmen.[4/] During these routine public contacts, the field assistant/patrolman made observations about the party at each site and during conversation noted such things as where they were from, what activities they were pursuing, if they had been to the area before, and so forth. Almost all the users were talkative; in fact, breaking off conversations was often much harder than starting them. In this manner we gathered observational data on 1,613 dispersed recreation parties, supplemented by conversations that evolved with 630 of them.

Table 4 indicates the following data for the parties contacted--observed and/or conversed with: (1) length of stay, (2) total parties using various kinds of camping equipment, (3) party size, (4) number of camping units per party, (5) total age distribution, (6) residence, (7) distance traveled to the area, (8) previous experience in the area, and (9) the proportion of parties with motorbikes or four-wheel drive vehicles and the total number of machines observed.

The limitations of these observational and conversational data must be kept in mind. They are not representative of all dispersed users. Although

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[4/] The field assistants were Mack Hogans at Upper Clackamas, University of Washington cooperative research assistants John Morrell at Taneum-Manastash, and Chris Christensen and Dan Wood at Greenwater. (Dan Wood is now recreation planner with the Bureau of Land Management at Cañon City, Colo.)

Table 4.--Selected characteristics of dispersed road recreation parties in three areas based on observations and conversational contact by patrolmen

Characteristics	Greenwater		Taneum-Manastash		Upper Clackamas		Total	
	No.	Percent	No.	Percent	No.	Percent	No.	Percent
1. Length of stay:								
Campers only								
2 days, 1 night	53	(32)	249	(53)	347	(65)	649	(56)
3 days, 2 nights	96	(57)	99	(21)	126	(24)	321	(27)
4 days, 3 nights	5	(3)	35	(7)	45	(9)	85	(7)
5 days and greater	13	(8)	90	(19)	13	(2)	116	(10)
No. of parties observed	162	(100)	473	(100)	531	(100)	1,171	(100)
Average stay of overnighters (nights)	2.1		3.1		1.6			
2. Total camping units observed:								
Tents	41	(16)	154	(23)	180	(25)	375	(23)
Pickup campers	74	(28)	232	(35)	218	(30)	524	(32)
Trailers	80	(31)	171	(25)	125	(17)	376	(23)
Motorhomes	22	(8)	21	(3)	25	(3)	68	(4)
Vans and buses	12	(5)	38	(6)	75	(11)	125	(7)
Open campers	11	(4)	21	(3)	94	(13)	126	(7)
Other	21	(8)	32	(5)	6	--	59	(4)
No. of parties observed	261	(100)	669	(100)	723	(100)	1,654	(100)
3. Party size:								
1	6	(4)	30	(6)	32	(12)	68	(7)
2	32	(19)	145	(30)	78	(28)	255	(28)
3	9	(6)	81	(17)	40	(14)	130	(14)
4-6	55	(33)	138	(29)	76	(28)	269	(29)
7 and greater	63	(38)	86	(18)	49	(18)	198	(22)
No. of parties observed	165	(100)	480	(100)	275	(100)	920	(100)
Aver. party size	6		4.8		4.6		5	
4. No. of camping units (tents and recreation vehicles per party)								
1	110	(62)	386	(69)	511	(71)	1,007	(69)
2	29	(16)	106	(19)	140	(19)	215	(19)
3	27	(15)	32	(6)	46	(6)	105	(7)
4-6	10	(6)	21	(4)	21	(3)	52	(4)
7 and greater	2	(1)	11	(2)	1	--	14	--
No. of parties observed	178	(100)	556	(100)	719	(100)	1,453	(100)
Aver. no. of camping units per party	1.8		1.6		1.3		1.5	
5. Age of participants:								
Adults	165	(57)	334	(62)	283	(64)	782	(62)
Teens	30	(11)	70	(13)	65	(15)	165	(13)
Children	93	(32)	131	(25)	96	(21)	320	(25)
No. of parties observed	288	(100)	535	(100)	444	(100)	1,267	(100)
6. User residence:								
Nearby community	24	(17)	65	(23)	13	(9)	102	(18)
Metropolitan	109	(80)	149	(52)	88	(64)	346	(62)
Other Washington (Greenwater and Taneum)	4	(3)	62	(22)	N/A		66	(12)
Other Oregon (Clackamas)	N/A		N/A		20	(15)	20	(4)
Out of state	0	(0)	9	(3)	16	(12)	25	(4)
No. of parties observed	137	(100)	285	(100)	137	(100)	559	(100)
7. Distance traveled (miles):								
0-50	38	(28)	64	(25)	19	(19)	121	(24)
51-100	94	(70)	129	(50)	75	(74)	302	(61)
101-150	2	(2)	50	(20)	0	(0)	52	(10)
151 and greater	0	(0)	12	(5)	7	(7)	19	(4)
No. of parties observed	134	(100)	255	(100)	101	(100)	490	(100)
8. Previous experience in study area:								
Yes	138	(95)	176	(89)	104	(88)	418	(91)
No	8	(5)	20	(11)	14	(12)	42	(9)
No. of parties observed	146	(100)	196	(100)	118	(100)	460	(100)
9. Special recreation equipment:								
Motorcycles								
No. and percent of parties observed with motorcycles	71	(41)	146	(22)	55	(7)	272	(12)
Total No. motorcycles observed	155		364		95		614	
Four-wheel drive vehicles:								
No. and percent of parties observed with four-wheel drives	13	(7)	99	(15)	25	(3)	137	(8)
Total No. four-wheel drives observed	27		141		33		201	

roads were systematically patrolled each day, our contacts constitute a convenience sample--we made observations or contacted users when and where we could. The data are strongly biased toward dispersed campers since most contacts were made at sites where users were camped. Only 26 percent of our contacts were with day users because they were often driving on roads or engaging in day activities that made contact difficult. Nevertheless, the data are informative, they provide the beginning of a user profile on dispersed campers and will be useful in planning and executing a representative survey of dispersed users during 1976. The data can be summarized as follows:

1. Length of Stay:

We collected length of stay information on 1,165 camping parties. More than half (55 percent) of the overnight campers stayed only one night and nearly 85 percent stayed two nights or less. Very few of the parties contacted stayed more than two nights, and most of them were in the Taneum area during hunting season.

2. Camping Equipment:

Of the 1,658 camping units we observed, pickup campers were the most popular (32 percent) followed by about equal proportions of tents and trailers (23 percent). For some reason, tents were more popular in Clackamas and trailers in Greenwater. Only 4 percent of the campers we observed had motorhomes; 7 percent had either vans, busses, or some other vehicle; and 7 percent camped in the open.

3. Party Size:

Party size varied from 1 to 60 people. There were many small parties of one or two persons (35 percent) and 14 percent had three persons. But there were also many larger parties--29 percent had four to six people, and 22 percent had seven persons or more.

4. Number of Camping Units per Party:

A large majority of the parties observed (69 percent) included only one camping unit--that is, one tent or one vehicle, etc.; 19 percent had two and 11 percent had three or more camping units.

5. Age:

A full spectrum of age groups appear to participate in dispersed camping. Among the 1,267 persons we observed closely enough to determine age, 62 percent were adults, 13 percent were teenagers, and 25 percent were children.

6-7. Residence, and Distance Traveled to the Area:

Most of the dispersed campers we contacted lived within a 2-hour drive of the study area. One-fourth of the campers lived within 50 miles of the study area, and 85 percent lived within 100 miles. Only 4 percent lived farther away than 150 miles. Eighteen percent came from nearby communities, 62 percent from the nearest large metroplitan area, either Portland or Seattle, 15 percent from elsewhere in the State, and only 4 percent from out of State.

8. Previous Experience:

A vast majority (91 percent) of the users had been to the same area before. Conversations with a number of them suggest that many users come back to the same areas a great many times.

9. Special Recreation Equipment:

We recorded data pertaining to motorbike and four-wheel drive use since there is particular concern about the impacts of these activities. Twelve percent of the parties we observed had a total of 272 motorbikes. Greenwater in particular was a motorbike area and 41 percent of the parties we observed there had at least one motorbike with them.

Of the parties observed, 8 percent had a total of 201 four-wheel drive vehicles.

We suspect that had our observations included more day users, we would have recorded more motorbikes and four-wheel vehicles. During the 1974 pilot study, we observed 540 motorbikes and 82 four-wheel drive vehicles in the Greenwater during just the Labor Day weekend.[5/]

We observed dispersed users engaging in a full range of activities, but we do not have the data to rank activities by popularity. The range of activities included: camping, fishing, hunting, hiking, berrypicking, woodcutting, motorbike riding, off-road vehicle use, horseback riding, swimming, rafting, painting, nature study, plant collection, mushroom hunting, sun bathing, drinking, socializing, playing games such as frisbee or horseshoes, and relaxing.

HUMAN WASTE IMPACTS FROM DISPERSED RECREATION

One other problem studied relates to the potential impact of human waste disposal from dispersed road recreation--a matter of concern to many managers we've talked to. In fact, the Upper-Clackamas study area was closed to dispersed camping a few years ago, in part to protect against potential impacts of human waste disposal on water quality. In conjunction with our research on dispersed road recreation, a separate 2-year study of human waste impacts is being conducted in the Greenwater area. Both biological and behavioral aspects of the problem are being studied to determine how extensive the impacts are and what human activity might be modified to control them.[6/] Following are some preliminary data that indicate the nature of the waste problem.

[5/] See Hogans (1974), footnote 2.

[6/] The behavioral aspects of the human waste problem is being studied under the supervision of Dr. Roger Clark of the Forest Service Recreation Research Project with Chris Christensen, doctoral student at the University of Washington. Biological and water quality aspects are being studied under a cooperative agreement between the Forest Service and Central Washington State College under the Supervision of Professor Robert Pacha.

A total of 72 campsites serving 371 camping parties and nearly 2,000 persons in the Greenwater drainage were studied to determine impacts from litter, garbage, sink waste water, and biological waste from humans and their domestic pets. Half the camping parties had either dogs or cats with them, two-thirds of which were allowed to run loose.

Based on a careful inspection of each site after each party left, only 10 percent of the parties left garbage and one-third left litter. The incentive system for litter control (Clark et al. 1972) was applied to these sites over Labor Day which reduced the litter level 65 percent.

About half of the parties with recreational vehicles did not contain their sink waste water but let it run out on the ground.

Two-thirds of the recreation vehicles did not have self-contained toilet facilities. More than half the parties left toilet tissue in the vicinity of the campsite. Toilet tissue was usually concentrated in 1 to 11 separate human waste areas near each campsite, with half of the tissue found within 50 feet of the campfire. In 82 percent of the toilet tissue occurrences, no fecal matter was found. We can conclude only that no fecal matter had been left, it had been buried, or was disturbed or consumed by animals.

The potential impact of waste disposal from dispersed road recreation is a priority topic for research. Information is needed on how extensive and serious the environmental, health, and esthetic impacts are and how they can be managed within acceptable tolerances.

SUMMARY AND CONCLUSION

The data presented in this paper come from only the 1st year of a 3-year study of dispersed road recreation in three case-study areas. Since the use data do not come from a representative sample, any conclusions must be regarded as tentative. The use data will be used to plan subsequent research. It highlights the need for a representative survey of users to determine more clearly: who they are, where they come from, how often and what kind of experiences they seek, what activities they engage in, what impacts result, what conflicts occur among recreation users and other resource uses. There is also a need to know how dispersed users feel about several resource management issues that may affect them including: sanitation, waste disposal, and water use, fire hazard and prevention, facilities at dispersed sites, contact with agency patrolmen, crowding, regulation or restrictions on use, road access, standards and potential road closures, and impact of timber harvest on the visual resource.

Only with more complete information on the above issues can dispersed recreation policy be developed by public and corporate landowners to optimize the resource costs and human values involved.

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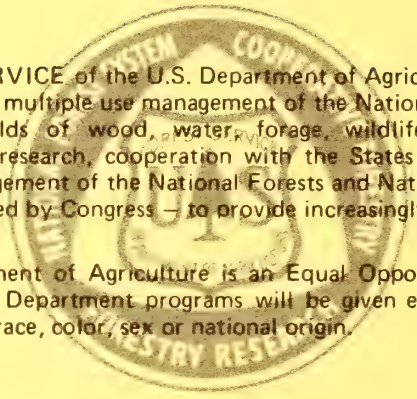

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AN IMPROVED TECHNIQUE FOR FREEZE SAMPLING STREAMBED SEDIMENTS

by

William J. Walkotten, *Forestry Research Technician*

JAN 6 1977

ABSTRACT

Equipment and operational improvements were made in the technique of freeze sampling stream sediments. The sampling procedure is routine, reproducible, and provides high quality samples. The equipment is now lighter, more reliable, and safer to use. The sediment sample obtained represents an undisturbed uniform vertical profile containing the bed material and water. Samples can be taken in deep water, through ice, and at other difficult locations. The equipment costs about $250.

KEYWORDS: Stream sampling, sedimentation.

INTRODUCTION

Freeze sampling (Walkotten 1973) provides the ability to sample in rocky streams, deep water, and arctic winter conditions (Lotspeich and Schallock 1974). The need to determine subtle environmental effects of sediment addition to salmon producing streams led to development and improvement of the freeze-sampling technique.

The technique provides an undisturbed sample with minimum disturbance of the sample area. The sample contains organic and inorganic material and intragravel water and retains sediment stratification.

Laboratory evaluation of this improved method compared with two other sampling methods[1] (McNeil and

[1] *Effects of land use in salmon production. Completion report, Commercial Fisheries and Development Act. Project No. 5-8-R and 5-19-R. Alaska Department of Fish and Game, Juneau. 1970.*

Ahnell 1960) in gravel of known composition, showed the freeze method to be the most accurate.[2]

Needed improvements in the original freeze-sampling technique became apparent as experience was gained with this method. It was difficult to control the high pressure liquid CO_2 accurately with conventional valves. This resulted in variable CO_2 use and plugging. Single point release of CO_2 also resulted in a "drop" shaped sample introducing possible bias. Modifications in the method were primarily concerned with improving sample quality. The use of an aluminum fire extinguisher for a supply tank reduces weight of the system. These changes provide the ability to closely meter the CO_2 at a known rate over time. The result is a reproducible testing procedure.

The sample probes are made from standard 3/4-inch harddrawn, type "M" copper pipe, a 3/4-inch brass or copper four-way cross fitting, and a tip machined from tool steel. The parts are soldered or brazed together.

The manifold parts are now commercially available (appendix B) and constructed to our specifications. Additionally, 4-foot-long manifold extension tubes are available if required. The filters are also available from commercial sources. Upon assembly, all nozzles and fittings on the manifold must be sealed with a thread sealer. This causes some difficulty when disassembling for repair or maintenance, but sealing is necessary to eliminate leaks at operating pressures.

[2]*Koski, K. Victor, and William J. Walkotten. Unpublished data on file at the Forestry Sciences Laboratory, Juneau.*

DESCRIPTION

Sampling is accomplished by freezing the substrate to a copper pipe probe inserted into the streambed (fig. 1). The rigid, thinwall copper pipe is mechanically strong and thermally conductive. Liquid CO_2 is released to atmospheric pressure from the manifold assembly placed inside the probe. The manifold distributes the CO_2 through metering nozzles over an area inside the probe that rapidly removes heat from the surrounding area in an even pattern. The manifold nozzles meter liquid CO_2 through #97 drill size (0.0057-inch) holes at a rate of about 0.2 lb/min per nozzle. The pressure drop and vaporization of CO_2 at the nozzle orifice causes rapid heat removal from the surrounding water and sediments, quickly freezing a core of sediment.

Operationally, the system is simpler and safer because a valve and some fittings are eliminated; and full pressure operation lets the entire system except the copper probe operate at ambient temperature. This greatly reduces the chance of component damage due to extreme thermal shock, keeps hoses flexible, reduces handling problems, and allows smaller size hose and fittings to be used. The addition of a 10-micron inline filter reduces the chance of plugging while sampling. This results in a smoother more reliable procedure with less maintenance. The elimination of a single point outlet for high pressure CO_2 lessens the chance of forcing the delivery manifold out of the probe.

The lower thermal conductivity of steel used in the probe tip causes a sharp cutoff of freezing at the bottom of the sample. This gives a more uniform shaped sample that is less biased by differences in size over depth.

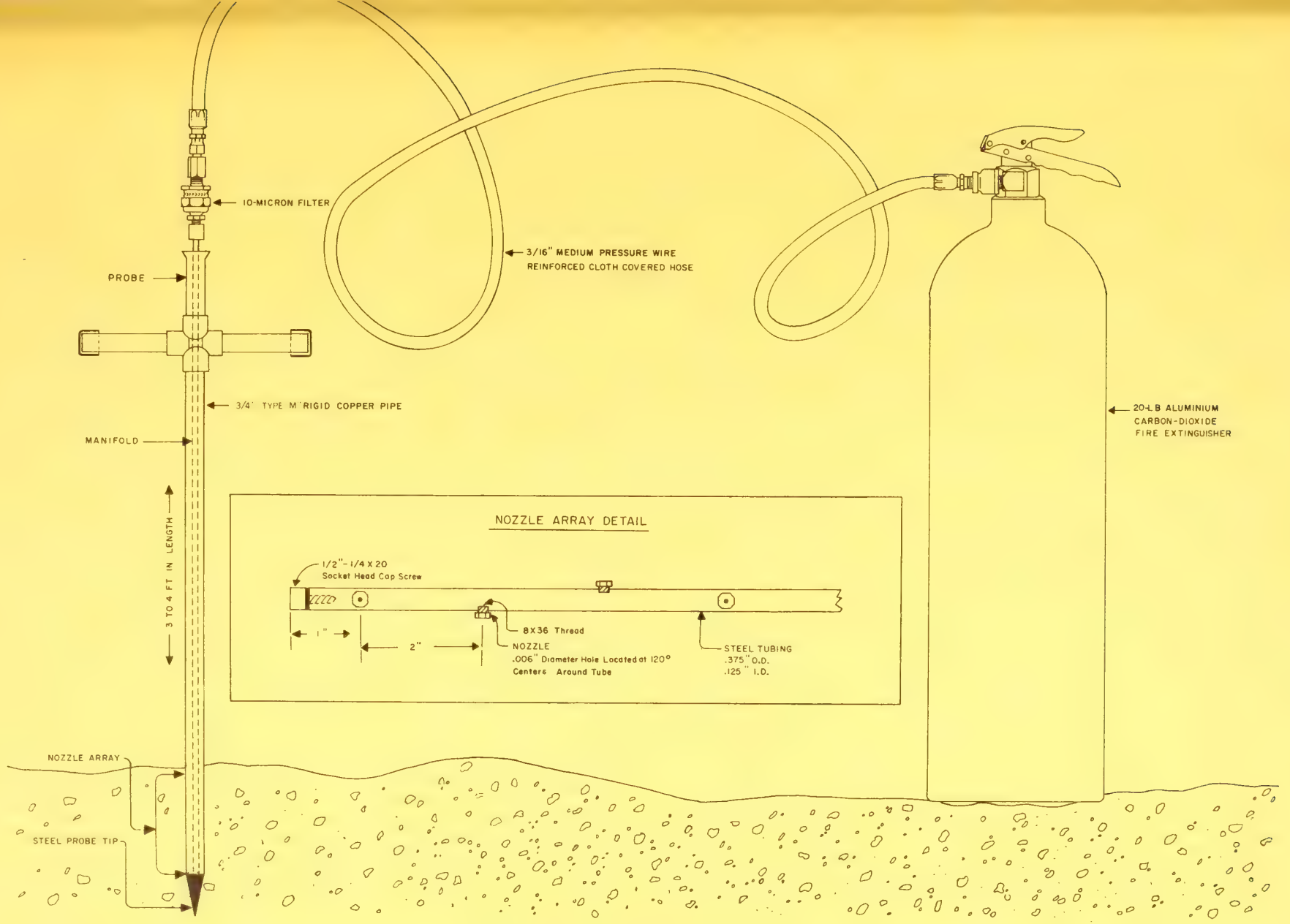

Figure 1.--Freeze sampling equipment showing probe, manifold, nozzle array detail, and CO_2 delivery system. The nozzles are located to release CO_2 below the gravel surface inside the copper probe.

PROBE AND MANIFOLD ASSEMBLY

The copper pipe probe (fig. 2) is made from standard 3/4-inch type "M" rigid copper pipe and fittings soldered together. A flared top is recommended to reduce the chance of shearing nozzles from the manifold when inserting it into the probe. The steel tip is machined for a tight fit inside the pipe and soldered in place.

The assembly of the manifold parts is important. The number of nozzles is determined by the chosen depth of the sample desired. Nozzle spacing on the manifold tube is determined by the area that a single nozzle can effectively freeze without noticeable change in the shape of the sediment sample. Testing showed this spacing to be about 2 inches. Nozzles are placed in the manifold from the bottom up to a point 2 to 3 inches below the streambed gravel surface. For example, four nozzles would be placed in the manifold for a 10-inch-deep sample,

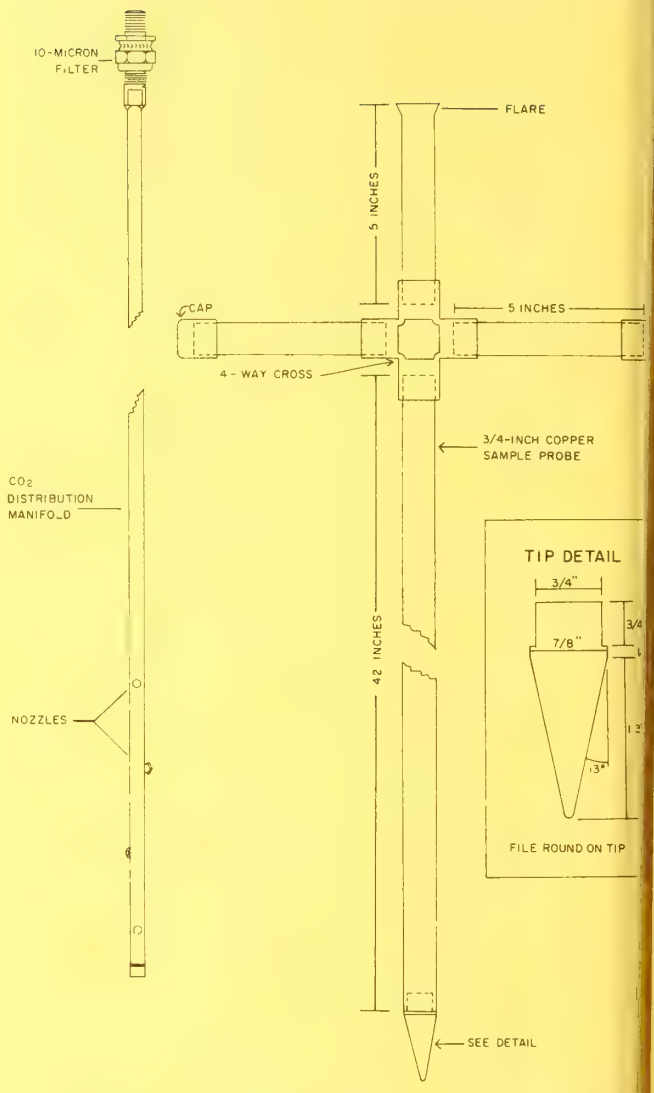

Figure 2.--Sampling probe and mainfold assembly.

and the rest of the holes would be filled with nozzle blanks. CO_2 use is about 0.2 lb/nozzle per minute so the above manifold assembly would release about 0.8 lb of CO_2 per minute of sampling.

After the sample site is selected, the copper probe is pushed into the streambed, the manifold assembly is inserted into the probe, and the CO_2 is turned on. Timing is all that is necessary to freeze the desired sample. The CO_2 is stopped, the manifold removed from the probe, and the probe and sample are pulled from the streambed. A good quality sample can be obtained in 4 minutes (table 1).

FIELD APPLICATION

This sampling method allows great flexibility in selecting sample locations and allows samples to be taken over a variety of bottom types, current velocities, and depths. This system allows the operator to either select random sites or utilize a carefully designed method of sampling.

If several copper probes are placed in the streambed prior to sampling, the manifold can be moved from one to another without turning the CO_2 off. A frozen sample can be extracted after the manifold is moved to the next probe and timing begins. Some preplanning is necessary to prevent a mixup of samples but total time spent sampling is reduced by this routine.

Table 1--*Timed CO_2 sampling tests using four nozzles at a 10-inch sample depth in laboratory blended gravel*

N = 3

Freeze time (minutes)	Mean diameter of freeze sample	Mean sample weight	Mean CO_2 used per sample	CO_2 used per kg sample	Gravel percentage passing through a 3.36 mm-sieve	
	cm	kg	- - - - [1/] lb - - - - -		Mean	Sample standard error
2	5.84	1.095	2.0	1.84	18.5	6.1
4	7.62	1.586	3.3	2.16	21.7	2.0
6	7.87	2.052	4.9	2.38	23.2	2.5
8	8.89	2.534	6.1	2.42	22.4	2.7
10	9.14	2.809	7.6	2.74	21.0	2.4
15	10.92	2.688	11.6	3.15	24.7	2.7

[1/] Carbon dioxide is bottled and sold on the commercial market by weight in pounds and is reported here in pounds used per sample for cost comparison purposes with local prices.

A hoisting or leverage device may be necessary to loosen the frozen core from the streambed if large samples are needed or if the depth of sediments is more than about 12 inches. A satisfactory lightweight tripod hoist (Gary 1976) can be fabricated using aluminum pipe and a small hand winch. It is necessary to weld a 4-inch-square plate on the bottom of the legs to prevent them from sinking into the gravel. Once the sample is broken loose from the streambed, it can usually be removed by lifting.

It is essential to supply the nozzles with liquid CO_2. A fire extinguisher bottle and some other storage cylinders have an internal tube extending to the bottom of the container so the discharge is liquid under pressure in the upright position. If cylinders with the internal tube cannot be obtained, the liquid CO_2 can be removed by inverting the tank.

ASSEMBLY AND USE

Assembly and Operation: If possible, set the CO_2 cylinder on level ground. Remove the safety pin; and while holding the cylinder firmly with the outlet pointed in a safe direction, tap the discharge lever to release a small amount of CO_2. This clears the valve of accumulated dirt and condensation. Apply thread lubricant on the hose fittings and attach hose and manifold assembly to the cylinder. Carefully tighten all fittings with a wrench. Holding the manifold away from the operator, turn on the CO_2 and check for leakage and plugged nozzles. If everything checks, carefully insert the manifold into the previously located copper probe, tie down with a nylon cord, and start timing.

The copper sample probe is placed in a selected location by pushing it to the desired depth by hand or by driving it down with a steel rod placed inside. The rod is driven with a hammer against the probe tip. The driving method of probe placement works unless the probe strikes a large rock, and then forcing the probe will only damage it. For sampling, attach about 10 inches of filament tape to the top of the discharge lever on the CO_2 cylinder, open the discharge valve, and tape it down. Sample timing should start when "snow" appears above the top of the probe which indicate that the liquid CO_2 is flowing through the nozzles and the freezing process has begun. After 4 minutes, release the tape holding the discharge lever down or switch the manifold to another sampling probe. Since the CO_2 discharge is through metering nozzles, the manifold can be removed while still operating and placed in another probe. This should be done carefully, and the operator must wear eye protection.

Remove the frozen sample probe from the streambed, using a lifting device if necessary, and place it in a plastic bag for thawing. Do not use a high temperature heat source such as a propane torch to heat the probe in an attempt to accelerate the thawing process. This anneals the rigid copper pipe so it will bend in use. Hot water poured into the probe works best if thawing must be hurried. Be sure to take notes and label samples at this time to prevent later mixups. Generally, four samples can be taken with a 20-lb cylinder, but is must be remembered that successful freezing will take place only when liquid CO_2 is delivered to the probe. When in doubt about the supply, the cylinder can be weighed in the field with a spring scale. A full 20-pound aluminum extinguisher bottle weighs 46 to 47 pounds so estimates on available supply can be made. Each nozzle releases CO_2 at a rate of about 0.2 lb per minute, and even a small leak in the system releases a large quantity of CO_2 compared to the nozzles. It is advisable to check for leaks and plugged nozzles whenever the manifold is placed in or removed from the probe.

Field sampling requires some accessory equipment along with the basic sampling gear. Experience has shown that a basic set of tools, parts and accessories assembled into a kit is necessary for field repairs and maintenance. Appendix A shows the recommended contents of such a kit.

MAINTENANCE AND SAFETY PRECAUTIONS

Use, transport, assembly, and operation of the equipment causes some damage and a certain amount of maintenance is always necessary to prevent loss of time. Since the CO_2 is in cylinders under pressure (830 PSIG at 70 °F), a potential hazard should be recognized; and although the cylinders can withstand normal handling, any chance of abuse (dropping, stripping threads, no safety caps on outlets, etc.) must be eliminated and questionable equipment should not be used.

Each CO_2 cylinder should be plumbed with steel fittings so that the hose can be changed without removing the pipe fittings from the aluminum valve housing. This prevents thread damage to the valve and is faster than removing the fittings. A pipe plug should be attached to each cylinder for plugging the fitting when the hose is removed.

It is only necessary to remove the hose from the CO_2 cylinder and manifold to prepare the sampler for shipment. It must be remembered that the CO_2 cylinders are still under pressure, and the outlet port needs to be plugged and the valve safety pin needs to be taped in place to prevent accidental discharge. Never bleed all the pressure from the cylinder as this may loosen the valve seals and cause leakage upon refill.

Some routine maintenance is necessary after about 50 samples. Remove the inline filter from the hose and manifold if plugging becomes a problem. Install the filter on a CO_2 cylinder using a 1/4-inch short pipe nipple with the flow arrow pointing toward the CO_2 cylinder to reverse normal direction of flow. Clean the filter by grasping the cylinder firmly and expelling a small amount of CO_2 through the filter. The filter can then be reinstalled on the manifold using a small amount of thread sealer on the fittings.

Periodically, and after any repair, remove the cap screw in the manifold and blow the hose and manifold clean. If nozzles plug and cannot be cleaned, remove them and check the screens. Plugged nozzles and screens must be replaced and the entire system blown clean. Experience has shown that badly contaminated CO_2 containing rust, dirt, water, and oil can occur. In that case, cylinder and valves must be cleaned. The supplier should be notified and should clean the cylinders. The recommended hose has removable fittings so repairs can be made in the field. If a leak develops, the fittings can be removed, the hose cut with a fine-tooth hacksaw, and the fittings replaced.

Nozzles can be broken off unless they are carefully removed with a well-fitting 7/32-inch socket wrench. The removable screen inside the nozzle can be replaced with a small rounded device such as a ballpoint pen tip. If a nozzle is broken off, it usually cannot be removed with an ezyout and must be drilled out with a #29 bit and the threads cleared with a #8x36 thread tap. This must be carefully done to prevent permanent damage to the manifold tube. A small amount of thread sealer is placed on all reassembled parts. The thread sealer will prevent leakage after it sets. Do not overtighten and strip the threads on the brass nozzles.

Repair or replace the copper probe if it becomes bent or leaks water. Normal use rarely causes damage to the probe, but forcing penetration with a driving rod can drive the point off the end of the tube, and cause the probe to

bend. If driving is used for a placement method, more damage should be expected and additional parts should be available.

In general, the sampling gear should be kept as clean and dry as possible, especially the internal parts of the CO_2 system. Care in handling equipment during shipment and sampling will reduce maintenance problems.

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APPENDIX A

RECOMMENDED FIELD SAMPLING AND MAINTENANCE EQUIPMENT LIST
FOR CO_2 SAMPLER

Sampler Equipment

3 ea. copper sample probes
1 ea. #MO297 CO_2 metering manifold assembly (CO_2 probe)
1 ea. hose assembly
2 ea. or more 20-lb. aluminum fire extinguisher bottles
1 pr. goggles or safety glasses
1 ea. probe driving rod, 5/8-inch diam. x 54 inches long
1 ea. driving hammer
1 ea. stopwatch
1 pr. gloves
1 roll filament tape
3- to 4-foot-length 1/8-inch nylon cord

General Tools and Equipment

1 ea. tool box
1 ea. 12-inch adjustable wrench
2 ea. 8- or 10-inch adjustable wrenches
1 ea. 4-inch adjustable wrench
1 ea. pocket knife
1 ea. 8-inch pipe wrench
1 ea. 50-lb spring scale
1 ea. pack board for transporting CO_2 cylinders
1 ea. pack for transporting sampling and maintenance gear
1 ea. tripod assembly (optional)

Maintenance Equipment

1 ea. #97 drill for cleaning nozzles
1 ea. #29 drill bit for drilling out broken nozzles
1 ea. 7/32-inch socket wrench
1 ea. 8-36 taper, plug & bottom thread tap set
1 ea. #1 screw extractor
1 ea. hacksaw with fine-tooth blade (32 per inch)
1 ea. large vice grips
1 ea. tube thread sealer
1 ea. tube thread lubricant
1 ea. small hand drill
2 ea. 1/4-inch short pipe nipples
1 ea. Gates 4C54RPM male hose fitting
1 ea. Gates 4C54RFSX fitting
1 ea. Gates 4F-4SMS adapter
12 ea. Modern MFG Co. MO2981 modified nozzles
6 ea. Modern MFG Co. MO2982 modified nozzle blanks
24 ea. Modern MFG Co. nozzle screens
1 ea. nozzle screen inserter (ballpoint pen)
1 ea. propane torch soldering kit
Spare solder, flux, & steel wool
1 ea. spare steel probe tip
1 ea. Linde Model SG - 6110 inline filter

APPENDIX B

FREEZE SAMPLER SUPPLY SOURCES[3] - 1975 PRICES

CO_2 manifold, nozzles, and accessories. Approximate cost: $90
Price schedule for MO297 CO_2 probe manifold:

NUMBER	PRICE EACH
25 & OVER	$65.00
20-24	70.00
15-19	75.00
10-14	80.00
1-9	85.00
MO298-1 Modified nozzles W/.0057 orifice	1.50
MO298-2 Modified nozzle blank	.75
4-foot extension manifold tube	32.25

The manufacturer lists the manifold as "MO297 CO_2 PROBE" for supply purposes. This does not include the copper sample probe.

Modern Manufacturing Inc.
815 Houser Way N.
Renton, WA 98055

(206) 228-4500

Inline Filter Model SG-6110 $18

Union Carbide Corporation
Lindie Division
One California St.
San Francisco, CA 94111

(415) 765-1322

Hose & fittings 4C5 Gates hose 15 to 20 feet @ $.97/ft
4C5-4RPM male fitting 1 each @ $.60 each
4C5-4RFSX fitting 1 each @ $.80
4F-4JMS adapter 1 each @ $.74

Nebar Supply Company Inc.
430 Minor Ave. N.
Seattle, WA 98109

(206) 622-6292

20-lb aluminum fire extinguisher, approximate cost: $50

United Fire Extinguisher Sales & Services
4611 N.E. Union Ave.
Portland, OR 97211

(503) 288-5716

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[3]*Trade names mentioned are for convenience of reader and do not imply endorsement by the U.S. Department of Agriculture.*

4-way brass or copper cross, 3/4-inch $5.50

Alaskan Copper & Brass Company
3223 Sixth Ave. S.
Seattle, WA 98108

(206) 623-5800

8x36 thread taps	Approximate cost each:	$1.00
8x36 thread die	Approximate cost each:	$1.25
#97 drill bit	Approximate cost each:	$1.50
#29 drill bit	Approximate cost each:	$1.00

Sterling Tool Company
4202 6th Avenue S.
Seattle, WA 98108

(206) 623-6891

Miscellaneous copper pipe, pipe fittings, tool steel, thread sealer, 7/32-inch socket wrench, solder, tools, etc. From local suppliers.

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YES, INCREASED YIELDS CAN REDUCE HARVESTS!

by

Enoch F. Bell, *Economist*

ABSTRACT

Increases in stand yields resulting from growth-stimulating or inventory-protecting silvicultural investments may actually reduce the allowable cut calculated by Timber RAM as presently used on National Forests. The case study presented here indicates that the timing of the silvicultural investment and the lack of flexibility with respect to the rotation and timing of thinnings affect the occurrence and severity of this unusual result.

KEYWORDS: Allowable cut, yield regulation, timber management planning, Timber RAM.

INTRODUCTION

The allowable cut effect (ACE) (Bell et al. 1975, Lundgren 1973, Schweitzer et al. 1972, and Teeguarden 1973) represents the change in present forest harvest level attributable to any action which changes timber yields at some time in the future. The effect is a direct result of harvest flow constraints on a forest and thus is also affected by changes in the severity of these constraints.

Traditionally the ACE for a silvicultural treatment has been measured in terms of the increase in mean annual increment that can be attributed to that treatment distributed equally over the rotation. This procedure often produces reasonable results for many of the harvest scheduling techniques used in the past, but the advent of Timber Resource Allocation Method (RAM) (Navon 1971) and other computer harvest scheduling models has made this procedure suspect. In actuality, the ACE in these models may range from a negative quantity to an increase as large as the increase in yields at the end of the rotation depending upon when the increase occurs.

To illustrate and explain this wide range in ACE, two alternatives for fertilization on a western National Forest were analyzed with the 1972 version of Timber RAM using the present Forest Service nondeclining even-flow policy. For the first alternative, a fertilizer application in conjunction with pre-commercial thinning on 28,480 acres (11,526 ha) of medium site Douglas-fir increased the final harvest after nine decades by 10 percent to 6,900 ft^3 per acre (483 m^3/ha). For the second alternative, the same treatment applied to 10,460 acres (4,233 ha) of high site Douglas-fir also increased the final harvest by 10 percent to 8,250 ft^3 per acre (577 m^3/ha) following an eight decade period.

The results of these treatments on the allowable cut are shown in table 1. If one uses the traditional measure of increased mean annual increment, both alternatives appear attractive, since mean annual increment increases in both cases. When using RAM, however, the results are quite different. In the case of the medium site Douglas-fir, the harvest in the first decade actually declines rather than increasing as one might expect. Furthermore, the results for the high site Douglas-fir, while positive, are not as large as might be expected from use of the traditional analysis.

Why do these results occur? Intuitively it is clear that when volume is constrained to be a certain level in a given decade, any increase in volume above that level will not be permitted. Because of increased volume per acre in the example above, fewer acres can be harvested before the constraint is reached. This means fewer acres will be available for harvest at a future date because only a few harvest and thinning schedules are allowed in RAM for regenerated timber. This reduction in acres harvested can become extremely significant and actually result in reduced future harvest. What is less obvious is how these changes relate to the first decade harvest when the critical period is in some later decade.

Timber RAM for National Forests generally maximizes harvest in the first decade subject to some flow constraints. The Pacific Northwest Region of the Forest Service constrains the harvest level in each decade to be not less than 99.9 percent of the harvest in the preceding decade during the conversion

Table 1--*Change in first decade harvest for two alternative fertilization levels measured by two methods*

Investment alternatives	Method of calculation	
	Mean annual increment	Timber RAM[1/]
	Cubic feet/acre (m^3/hectare)	Cubic feet/acre (m^3/hectare)
1. On medium site Douglas-fir[2/]	+37 (+2.6)	-7 (-0.5)
2. On high site Douglas-fir[3/]	+94 (+6.6)	+60 (+4.2)

[1/] Daniel Navon, 1971. Timber RAM...a long range planning method for commercial timberlands under multiple use management, USDA For. Serv. Res. Pap. PSW-70. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

[2/] Fertilize 28,480 acres (11,526 ha) of medium site Douglas-fir to increase final harvest in nine decades by 10 percent.

[3/] Fertilize 10,460 acres (4,233 ha) of high site Douglas-fir to increase final harvest in eight decades by 10 percent.

period. Private industry may consider other less restrictive flow constraints. In any case, linking the decades together by constraints means that what happens in future decades affects the previous decades in proportion to the severity of the flow constraints.

In more technical terms, the nonbasis of the final linear programing tableau provides other clues to the results. Table 2 shows the shadow prices for the volume variable in Timber RAM for the example presented above. When the objective is to maximize first decade harvest, the shadow price for a given decade indicates the increase (or decrease) in first decade harvest that would result from a unit increase (or decrease) in volume during that decade. Because of the way the model is set up, negative signs should be interpreted as reflecting direct relationships whereas positive signs indicate inverse relationships. For example, the positive sign for the decade nine shadow price indicates that increases in volume in decade nine will result in decreases in harvest during the first decade--a situation described in table 1. Unfortunately, the large number of constraints and activities in the model often restrict the range over which the shadow prices are relevant. That is, large changes in volume will likely change the linear programing basis and thus, the shadow prices.

The unusual allowable cut effect shown in table 1 is not unique to this case study. Analysis of eight western National Forests under alternative flow restrictions, ranging from nondeclining even flow to 5-percent declining flow and 10-percent fluctuating flow around an average, indicate that these

Table 2--*Final nonbasis linear programing results for case study volume variables by period*

Period	RAM volume variable name	Shadow price
1	VOLU1	-0.071
2	VOLU2	- .072
3	VOLU3	- .073
4	VOLU4	- .086
5	VOLU5	- .090
6	VOLU6	- .086
7	VOLU7	- .084
8	VOLU8	- .081
9	VOLU9	+ .034
10	VOLUA	+ .007
11	VOLUB	- .001
12	VOLUC	- .001

unexpected results should be expected. Five out of the eight Forests under all types of flow constraints had some decades where increased volume would reduce the even flow harvest level. The other Forests had these decades only under certain flow constraints. Unfortunately no pattern appears to exist which might allow prediction of these situations.

In addition, since Timber RAM has received such widespread use among both public and private sectors, the implications of these results must be considered significant. Some of these include:

1. Practices which increase growth may not increase harvest and in some cases may even decrease it; e.g., precommercial thinning may reduce the even flow harvest level.

2. Factors which reduce growth or inventory such as insects, diseases, or fires may make increased even flow harvest levels possible; e.g., bugs and fires should be allowed to progress in some cases.

3. Rescheduling of thinnings, although not changing growth, may increase or decrease the harvest level. Changes in rotation age may also have the same effect, even though these changes are away from culmination of mean annual increment.

In conclusion, the allowable cut effect in Timber RAM depends upon the period in which the action producing the ACE occurs. No longer can investments in silvicultural and other forest practices on forests where harvests are scheduled subject to flow constraints be evaluated without considering the time of their implementation. Just as there is an optimal timber harvest schedule, there is also an optimal investment schedule, and the timing of the investment is critical in determining the amount of the allowable cut effect. The problem of scheduling investments is further complicated by the limited rotation and thinning alternatives for regenerated timber available in RAM. Because of this limitation, increased yields can actually reduce harvests in some cases.

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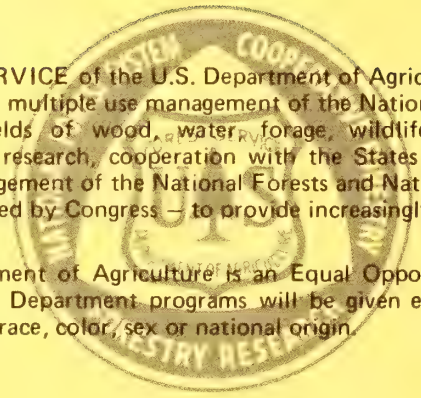

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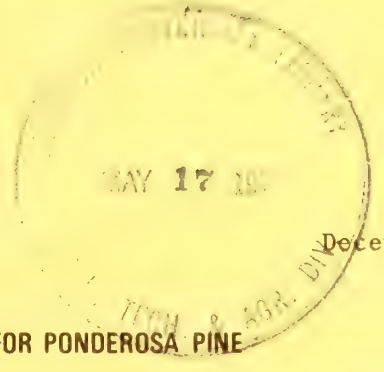

PNW-283 December 1976

PREDICTING WOOD VOLUMES FOR PONDEROSA PINE FROM OUTSIDE BARK MEASUREMENTS

by

P. H. Cochran, *Principal Research Soil Scientist*

ABSTRACT

Assumption of a constant diameter inside bark to diameter outside bark ratio along the bole of ponderosa pine results in an underestimate of wood volume determined from optical dendrometer measurements in the STX program. This ratio gradually increases up the stem to a given diameter outside bark to diameter breast high outside bark ratio that varies with tree size and then decreases to the tip. Equations describing this change in bark thickness can be incorporated into the STX program. Resulting estimates of diameters inside bark, volume segments, and whole tree volumes are closer to true values than estimates derived by the constant ratio assumption.

KEYWORDS: Volume estimation (tree), volume determination methods, bark thickness, computer programs, STX, ponderosa pine.

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

INTRODUCTION

Many studies in the Pacific Northwest are concerned with the response of sapling-, pole-, and small sawtimber-size ponderosa pine[1/] trees to thinning, fertilization, and treatment of understory vegetation. Assessment of treatment effects on wood production requires conversion of diameter outside bark (dob) at several points along the bole (usually determined with optical dendrometers) to diameter inside bark (dib) used in calculating wood volumes for standing trees.

In Grosenbaugh's (1964) STX program for processing tree measurements, three options are available for the dob to dib conversion: (1) a constant ratio option assuming a uniform dib/dob ratio along the bole; (2) an option assuming that dib/dob increases curvilinearly above diameter breast high (dbh) and decreases curvilinearly below dbh; (3) an option assuming that dib/dob decreases curvilinearly above dbh and increases curvilinearly below dbh. These options use field determinations of dbhib and dbhob.

The constant ratio option (option 1) has been used in the Pacific Northwest for ponderosa pine without evidence to support its use. Wiant and Koch (1974) found that the constant ratio option was most accurate for yellow poplar, red maple, northern red oak, black oak, and scarlet oak. Mesavage (1969) concluded that the second option was best for estimating volumes of loblolly, shortleaf, slash, and longleaf pines.

Grosenbaugh (1964) did arrange his program to receive user supplied options, and the literature indicates that none of the three options describe the change in bark thickness along the bole for some conifers. Saikku (1973, figs. 4 and 5) found that bark thickness of Scots pine decreased with height up the stem below about 6 meters. From between 4 and 6 m to the tip (14 to 20 m), bark thickness remained constant (about 5 m). MacDonald (1973) examined outside and inside bark girths along the bole of Scots pine, Douglas-fir, Sitka spruce, Norway spruce, and European larch. He found in general that the ratio

$$\frac{\text{girth outside bark-girth inside bark}}{\text{girth outside bark}} \times 100$$

decreased with increasing distance above dbh through the lower third of the bole, remained nearly constant from one-third to one-half of the stem, and then increased in the upper one-half of the stem. Brickell (1970) mentioned that the dib/dob ratio may increase, remain nearly constant, then decrease as measurement progresses up the stem. An algebraic rearrangement of Brickell's equation (5) which covers this possibility is

$$\text{dib/dob}=1-\left(\frac{\text{dbhob-dbhib}}{\text{dob}}\right)\left(\frac{b-1}{b-\text{dob/dbhob}}\right). \qquad (1)$$

Another equation derived in this study, which also describes this pattern of dib/dob along the stem, is

$$\text{dib/dob}=(\text{dbhib/dbhob})\left[1+(\text{dob/dbhob})^{a-b(\text{dob/dbhob})}-(\text{dob/dbhob})^{c-d(\text{dob/dbhob})}\right]. \quad (2$$

METHODS

Data for different sites and sizes and ages of trees were collected in Oregon and Washington to determine patterns of dib/dob variation along stems. For each location, at least 10 trees were felled. Age at 1-foot[2/] stump and

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1/ Scientific names of trees mentioned are listed on page 8.

2/ Metric unit conversion factors are listed on page 8.

total height to the nearest 0.1 foot were determined. Nails were driven at the 1-foot stump, dbh, and at decile height intervals from dbh to the tip. Diameter ob measurements were taken at these points with a caliper while the inside edge of the graduated portion of the caliper was resting on the nailhead. Then patches of bark were peeled, exposing the wood at 90 and 270 degrees around the bole from the nail, allowing the dib measurements to be made with calipers, again resting on the nail. For each tree, these dob and dib measurements were taken to the nearest 0.05 inch for 11 locations along the bole including stump and dbh.

Diameter ib/dob ratios were calculated for each point on each tree and then plotted as a function of dob/dbhob. Diameter ib/dob ratios gradually increased up the stem to a given dob/dbhob which varied with tree size, then gradually decreased for points progressively farther up the tree. None of the three options in the STX program appeared to describe the resulting pattern. Both equations (1) and (2) resulted in significant fits for points above dbh. Equation (1) could not always be fit significantly to points below dbh. Bark thickness at stump was highly variable for small sawtimber-size trees and not always predictable from dbhib/dbhob. Fortunately, stump bark thickness can be sampled directly in field studies.

Ponderosa pine is a rough-barked species resulting in considerable variability in dib/dob. Equations (1) and (2) were rearranged so that factor (dib/dob)/(dbhib-dbhob) for equation (1) and factor (dib/dob)/(dbhib/dbhob) for equation (2) could be fitted as a function of dob/dbhob for groups of at least 10 trees of similar sizes for each sample location. This rearrangement forces the curves through the point (1, 1) for each tree where dob equals dbhob and produces more homogeneous variances. Fitting by iteration to minimize the sums of squares of the residuals was done as though all data points were independent. Coefficient b in equation (1) and coefficients a, b, c, and d in equation (2) were determined for 10 separate size classes sampled east of the Cascades in Oregon and Washington. Coefficient b in equation (1) and coefficient a in equation (2) varied with tree size. Coefficients b, c, and d in equation (2) did not appear to vary with tree size.

Coefficients b (equation 1) and a (equation 2) were functions of the average dbh in inches squared times total height in feet (D^2H) for the 10 or more trees used in their derivation. Equations (1) and (2) with their coefficients were then tested with more tree data collected in additional areas of Oregon and Washington. Diameters ib for these test trees were measured directly and also calculated from corresponding dob's using the constant ratio assumption as well as equations (1) and (2) (after shifting the dob term from the left- to the right-hand side) with respective coefficients b and a determined using the D^2H for each tree. Volumes for stem segments above dbh were then calculated using actual and estimated dib's with Smalian's formula. Volumes of individual tree segments were summed to obtain whole tree volumes above dbh. These calculations were repeated to include the stump dib's, stump to dbh volume segments, and whole tree volumes above stump.

In a further test 206 trees were sampled on the Deschutes National Forest by the timber management staff. Form class (dib at 16 feet above stump height divided by dbhob) was calculated using actual dib's at 16 feet above stump and the dib's estimated from these 16-foot dob's using option 1 and equations (1) and (2).

Comparisons of dib's, volume segments, and whole tree volumes arising from application of the constant ratio assumption as well as equations (1) and (2) were made from calculations of the root mean square deviation (RMSD):

$$\text{RMSD} = \sqrt{\frac{\Sigma(\text{actual value} - \text{estimated value})^2}{\text{number of estimates}}} \qquad (3)$$

for corresponding sets of data. The lower the root mean square deviation for a set of estimated values the closer those values are to the actual values. Freese's (1960) test of accuracy was also applied to estimated whole tree volumes to separate the bias and lack of precision components of inaccuracy where accuracy was not within defined acceptable limits.

RESULTS AND DISCUSSION

The relationship between coefficient b of equation (1) and D^2H for ponderosa pine in the Pacific Northwest is

$$\log_{10} b = 0.280187646 - 0.040677437(\log D^2H). \quad (4)$$

The relationship between coefficient a of equation (2) and D^2H is

$$\log_{10} a = -0.335135683 - 0.062052639(\log D^2H). \quad (5)$$

The r^2 and F values were 0.73 and 26.42 for regression (4) and 0.65 and 18.67 for regression (5). Coefficients b, c, and d for Northwest ponderosa pine are 0.8037, 0.2111, and 0.5638. Application of equations (1), (2), and the constant ratio option to the 114 trees used in defining the coefficients showed that application of equation (1) was superior to equation (2) in predicting dib's, volume segments, and whole tree volumes above dbh. The constant ratio option (option 1 in the STX program) was far inferior to equations (1) and (2), resulting in a 7.03-percent underestimate of total actual volume and much higher root mean square deviations for dib's, volume segments, and whole tree volumes (table 1).

At each of 39 locations east of the Cascades in Oregon and Washington, 5 to 20 additional trees were sampled to test the equations.

Trees were sampled on every National Forest and on the Warm Springs and Spokane Indian Reservations. Site index[3/] for the sample locations ranged from 67 to 138, representing the range found in eastern Oregon and Washington. Trees in "very small" and "small" size classes (tables 2 and 3) were sampled in the same way as the trees used in deriving equations (4) and (5). Trees in the larger size classes were sampled for site index and yield studies conducted by James W. Barrett, research forester, at the Silviculture Laboratory in Bend. Diameter ob and dib measurements for these trees were taken on sections cut at 1 foot, dbh, 10 feet, and then at 5- or 10-foot intervals up the stem, depending on tree size. Of these "large" trees, 64 had much greater D^2H's than the largest trees used in defining coefficients in equations (1) and (2) (table 2).

For trees with D^2H's larger than 960, the constant ratio option is clearly inferior to both equations (1) and (2) for determining dib's and volumes above dbh (tables 2 and 3). Root mean square deviations were higher for these dib's, and volumes determined by option (1) and total volumes were underestimated. For the "very small" size class, differences between the three methods of determining dib's and volumes are slight; but option 1 was more accurate for a greater number of trees than either equation (table 3). Root mean squares for diameters, volume segments, and whole tree volumes for all but the smallest size class are lower for equation (1) than equation (2) (table 2). Equation (1) did a better job of estimating dib's and volume segments for more trees in the two largest size classes than did equation (2) (table 3).

[3/] Barrett, James W. Site index curves for managed stands of ponderosa pine. Unpublished data on file at Pacific Northwest Forest and Range Experiment Station, Silviculture Laboratory, Bend, Oreg.

Table 1--*Total volumes above dbh, differences between actual and estimated volumes above dbh, and root mean square deviations for dib's, volume segments, and whole tree volumes above dbh for 114 trees used in defining the coefficients in equations (1) and (2)*

Total actual volume (cubic feet)	Difference between estimated and actual total volumes			Root mean square deviations								
				Diameters			Volume segments			Whole tree volumes		
	Constant ratio option	Eq.(1)	Eq.(2)	Constant ratio option	Eq.(1)	Eq.(2)	Constant ratio option	Eq.(1)	Eq.(2)	Constant ratio option	Eq.(1)	Eq.(2)
	Percent			Inches			Cubic feet					
1,265.35	-7.03	-0.21	-0.79	0.267	0.150	0.171	0.198	0.077	0.112	1.650	0.559	0.826

Table 2--*Total volumes above dbh, differences between estimated and actual volumes above dbh, and root mean square deviations for dib's, volume segments, and whole tree volumes above dbh*

Size class[1/]	Number of trees in test	Total actual volume	Difference between estimated and total actual volumes			Root mean square deviations								
						Diameters			Volume segments			Whole tree volumes		
			CR[2/]	Eq. (1)	Eq. (2)	CR[2/]	Eq. (1)	Eq. (2)	CR[2/]	(Eq. (1)	Eq. (2)	CR[2/]	Eq. (1)	Eq. (2)
		Cubic feet	Percent			Inches			Cubic feet					
Very small[3/]	69	76.31	-1.32	+2.15	+1.87	0.092	0.096	0.092	0.007	0.007	0.007	0.057	0.050	0.053
Small[4/]	95	216.12	-4.88	-.76	-1.06	.171	.142	.142	.025	.015	.017	.205	.124	.144
Medium[5/]	200	2,979.16	-5.34	+.69	+.79	.282	.169	.179	.212	.110	.132	1.185	.574	.716
Large[6/]	64	7,142.60	-6.32	+1.72	+1.43	.638	.367	.472	.759	.419	.513	9.673	4.841	6.036

[1/] Average D^2H is the average for the 5 to 20 trees sampled at each location.

[2/] Constant ratio option.

[3/] Average D^2H ranged from 436 to 959 in^2 ft.

[4/] Average D^2H ranged from 1,044 to 2,642 in^2 ft.

[5/] Average D^2H ranged from 2,400 to 11,300 in^2 ft.

[6/] Average D^2H ranged from 35,000 to 149,000 in^2 ft.

Table 3--*Number of test trees by size class and by equations (1) and (2) when these equations produced estimates closer to true values than did the constant ratio option*

Size class	Trees	Equation (1)			Equation (2)		
		Dib's	Volume segments	Total volume	Dib's	Volume segments	Total volume
Very small[1/]	69	21	25	27	30	27	26
Small[2/]	95	67	63	64	67	64	66
Medium[3/]	200	162	168	166	160	163	161
Large[4/]	64	43	47	46	39	46	49
Total	428	293	303	303	296	300	302

[1/] Average D^2H ranged from 436 to 959 in^2 ft.

[2/] Average D^2H ranged from 1,044 to 2,642 in^2 ft.

[3/] Average D^2H ranged from 2,400 to 11,300 in^2 ft.

[4/] Average D^2H ranged from 35,000 to 149,000 in^2 ft.

For the 206 trees used to estimate form class, dbh varied from 11.5 to 47.3 inches and heights ranged from 60 to 160 feet. Many of these trees were larger than those used in defining coefficients in equations (1) and (2). Actual form class for these trees was 0.795. Calculated form classes using dib's determined by equations (1) and (2) and the constant ratio option were 0.801, 0.794, and 0.773. RMSD's for calculated dib's at 16 feet were 0.579, 0.620, and 0.811 for equations (1), (2), and the constant ratio option.

The underestimates of volume above dbh that result when the constant ratio option is used to determine dib's become more serious as tree size increases (table 2). Freese's (1960) test shows that this is not a precision error but a bias error. This bias arises because the bark thickness in the middle of the bole is thinner than predicted by the constant ratio method. This error suggests that, when stump bark thickness is not directly available from past dendrometer measurements, volumes should be recalculated for ongoing studies if a reasonable way to estimate stump dib's is available. Use of equation (1) to predict dib's from dob's larger than dbhob may result in serious error because the ratio dob/dbhob can be very close to the value for the b coefficient which is greater than 1. When this occurs, the factor (b-dob/dbhob) in equation (1) can be a very small negative or positive number resulting in a calculated dib that can be much too large--the usual case--or small. This leaves equation (2) to determine all dib's or equation (1) or (2) to estimate dib's above dbh combined with the constant ratio option to estimate stump dib's from dbhob and dbhib. Each of these methods produces reasonable results (table 4), but the errors resulting from application of equation (1) alone are quite evident. Except for the "very small" size class, the lowest root mean square deviations were produced when equation (1) was used for dib's above dbh in combination with the constant ratio option for stump dib's (table 4). It should be pointed out that it is possible to have errors for dib's above dbh when equation (1) is applied in the case of unusual stems with swelling of the bole above dbh.

Table 4--*Total actual volumes, differences between estimated and actual volumes above stump, and root mean square deviations for dib's, volume segments, and whole tree volumes for the test trees*[1/]

Size class	Total actual volume	Difference between estimated and total actual volumes			Root mean square deviations								
					Diameters			Volume segments			Whole tree volumes		
		CR[2/]	Eq. (1)	Eq. (2)	CR[2/]	Eq. (1)	Eq. (2)	CR[2/]	(Eq. (1)	Eq. (2)	CR[2/]	Eq. (1)	Eq. (2)
	Cubic feet	Percent			Inches			Cubic feet					
Very small[3/]	101.10	0.44	-2.14	+1.67	0.122	0.499	0.096	0.011	0.026	0.007	0.057	0.070	0.055
			+3.05	+2.85		.124	.122		.010	.010		.068	.068
Small[4/]	264.11	-2.82	-2.13	-0.65	.200	.932	.149	.027	.169	.018	.185	.571	.145
			+0.56	+0.31		.179	.178		.020	.022		.126	.144
Medium[5/]	3,531.97	-4.48	+427.64	-.16	.288	37.48	.327	.214	260.23	.154	1.191	674.93	.673
			+.62	+.70		.201	.208		.115	.136		.576	.720
Large[6/]	7,764.92	-5.68	+32.78	+1.02	.599	13.98	.521	.756	51.87	.529	9.456	224.862	6.042
			+1.73	1.46		.412	.498		.433	.524		5.077	6.300

[1/] The first row for each size class presents values determined by using the constant ratio option or equations (1) and (2) to calculate all dib's. The second row for each size class presents values where stump dib's were determined with the constant ratio option in every case.

[2/] Constant ratio option.

[3/] Average D^2H ranged from 436 to 959 in^2 ft.

[4/] Average D^2H ranged from 1,044 to 2,642 in^2 ft.

[5/] Average D^2H ranged from 2,400 to 11,300 in^2 ft.

[6/] Average D^2H ranged from 35,000 to 149,000 in^2 ft.

Setting required accuracy equal to 10 percent of the volume of the average size tree within each size class in table 4 (0.14, 0.30, 1.8, and 12 cubic feet for the "very small" to "large" size classes. Freese's (1960) test can be applied to the whole tree volumes estimated by each method. Resulting chi-square values (table 5) show that the constant ratio method is biased for all but the smallest size class. Use of equations (1) and (2) for dib's above dbh combined with the constant ratio for stump dib's produces estimated values for individual trees within the required limits unless a 1-to-20 chance has occurred.

Table 5--*Chi-square values for Freese's (1960) test of accuracy comparing measurements of whole tree volumes above stump*[1/] *with true values*

Size class[2/]	Constant ratio option	Equation (1)	Equation (2)	Constant ratio option-bias
Very small[3/]	43.904*	62.525*	62.525*	43.342*
Small[4/]	138.783	64.378*	84.085*	118.859*
Medium[5/]	336.373	78.676*	122.931*	166.170*
Large[6/]	152.667	44.009*	67.766*	71.590*

1/ Determined by the constant ratio option and equations (1) and (2) for dib above dbh and by the constant ratio option for stump dib. Asterisks indicate that accuracy standards were met at the 5-percent level of probability.

2/ Accepted standards were that each tree would fall within 0.14, 0.30, 1.8, or 12 cubic feet of the true value for the smallest to the largest size class unless a 1-in-20 chance occurred.

3/ Average D^2H ranged from 436 to 959 in^2 ft.

4/ Average D^2H ranged from 1,044 to 2,642 in^2 ft.

5/ Average D^2H ranged from 2,400 to 11,300 in^2 ft.

6/ Average D^2H ranged from 35,000 to 149,000 in^2 ft.

CONCLUSIONS

None of the three options in Grosenbaugh's (1964) STX program appear to describe the variation in dib/dob along the boles of ponderosa pine east of the Cascades in Oregon and Washington. The two equations presented here produce lower root mean square deviations for dib than did the constant ratio option which was formerly used. Equation (1) was originally presented by Brickell (1970) without recognition that coefficient b varied with tree size and results in lower root mean square deviations than equation (2) for dib's above dbh for all but "very small" trees. Equation (1) may produce errors for dib's estimated from dob's greater than dbhob. Both equations have one coefficient which varies with D^2H since dib's are predicted at various points along boles of trees with varying heights and forms from a dib and dob measurement at a fixed location. Use of the constant ratio option results in biased estimates of wood volumes which are low for all but "very small" trees. Thus, growth increments in past ponderosa pine studies probably have been slightly underestimated.

Preliminary investigation indicates these equations work with lodgepole pine in Oregon (where equation (2) appears superior to equation (1)) and ponderosa pine from the Black Hills, although the coefficients are different. Since the STX program is widely used, usually with one of the three listed options, investigators elsewhere should be aware that perhaps other equations may more accurately describe dib/dob variation along boles of the species they work with.

METRIC CONVERSIONS

1 inch = 2.54 centimeters

1 foot = 0.3048 meter

1 D^2H (in^2 ft) = 1.9664 cm^2 m

When D^2H is expressed in cm^2 m rather than in^2 ft, equations (4) and (5) are, respectively,

$$\log b = 0.280187646 - 0.04677437 (\log (0.5085 D^2H)),$$

and

$$\log a = -0.335135683 - 0.062052639 (\log (0.5085 D^2H)).$$

COMMON AND SCIENTIFIC NAMES OF TREES

ponderosa pine	*Pinus ponderosa* Laws.
yellow-poplar	*Liriodendron tulipifera* L.
red maple	*Acer rubrum* L.
northern red oak	*Quercus rubra* L.
black oak	*Quercus velutina* Lam.
scarlet oak	*Quercus coccinea* Muenchh.
loblolly pine	*Pinus taeda* L.
shortleaf pine	*Pinus echinata* Mill.
slash pine	*Pinus elliottii* Engelm.
longleaf pine	*Pinus palustris* Mill.
Scots pine	*Pinus silvestris* L.
Sitka spruce	*Picea sitchensis* (Bong.) Carr.
Norway spruce	*Picea abies* (L.) Karst.
European larch	*Larix decidua* Mill.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
lodgepole pine	*Pinus contorta* Dougl.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

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HERBICIDES FOR CONTROL OF WESTERN SWORDFERN AND WESTERN BRACKEN

by

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ABSTRACT

Dicamba at 3 pounds acid equivalent per 100 gallons of carrier will control individual western swordfern plants when applied between mid-May and late July. A mid-July foliage spray containing 1 to 3 pounds active ingredient per acre of asulam will produce good long-term control of western bracken without significantly affecting Douglas-firs or ponderosa pines.

KEYWORDS: Herbicides, brush control, swordfern, *Polystichum munitum*, bracken fern, *Pteridium aquilinum* var. *pubescens*, Douglas-fir, ponderosa pine, dicamba, asulam.

INTRODUCTION

Western swordfern (*Polystichum munitum*) and western bracken (*Pteridium aquilinum* var. *pubescens*) are common herbaceous species on forest lands in western Oregon and Washington. The effect of competition from bracken on conifer seedling establishment is well documented (Dimock 1964, McCulloch 1942, Staebler et al. 1954, Stewart 1975, Worthington 1955) but is unknown for swordfern. Swordfern is known to be a major winter food for a tree-damaging mammal, mountain beaver (*Aplodontia rufa*) (Voth 1968). This suggests that abundance of swordfern may affect mountain beaver populations. Recent evidence shows that reclamation of red alder (*Alnus rubra* Bong.) stands with swordfern understories can be difficult (Dimock et al. 1976). Reduction or elimination of swordfern and bracken from conifer plantations may reduce their desirability as habitat for tree-damaging animals and competition for light and soil moisture.

Western swordfern is found on forest lands in limited geographic areas and has not been considered a serious competitor to seedlings. Nothing was

known about its control. In contrast, varieties of bracken are a serious problem in pastures and on forest lands throughout the world. Although information on response of western bracken to herbicides was available (Fechtig 1968, Fechtig and Furtick 1965, Homesley and Furtick 1968, Robocker 1971), satisfactory treatments for controlling this species had not been been developed.

Beginning in 1970, a series of studies were installed to develop herbicidal treatments to control western swordfern and western bracken. Since swordfern is likely to require control only in localized areas, efforts were directed toward developing individual plant treatments. Bracken is a more widespread problem requiring treatments suitable for broadcast application.

All studies were installed as completely randomized experiments and the results analyzed by analysis of variance. Comparisons of herbicide effectiveness were based on analysis of percentage of plants killed for western swordfern and percentage of ground cover for western bracken.

WESTERN SWORDFERN

During the 1970 growing season, four herbicides were tested as foliage sprays on western swordfern near Sitkum, Oregon. Each treatment was applied in a water carrier by knapsack sprayer to drip point on 10 individual plants. Herbicides were applied as early foliar sprays on May 26, when fronds were at a mid- to late-hook stage, or as midsummer sprays on July 28, when fronds were mature and sori were yellow to rust colored. Results observed in September 1971, 13 to 15 months after treatment, are shown in table 1.

Swordfern was equally susceptible to sprays applied in late spring and midsummer, but there was a significant

Table 1--*Effects of herbicides as early foliar or midsummer sprays on western swordfern, 13 to 15 months after treatment*

Herbicide	Concentration	Early foliar spray			Midsummer spray		
		Plants killed	No. of fronds per live plant	Average frond height	Plants killed	No. of fronds per live plant	Average frond height
	lb aihg[1/]	Percent		Inches	Percent		Inches
Untreated	0	0	47	26	0	47	26
Picloram	1	0	24	18	0	35	19
	2	40	24	17	20	29	21
Dicamba	4	80	20	23	30	21	17
	8	80	36	20	90	6	11
Dichlobenil	4	20	15	23	30	16	23
	8	60	10	18	50	18	23
Bromacil	12	100	0	0	90	17	19

[1/] Pounds of active ingredient per 100 gallons of water.

difference in plant kill obtained with the four herbicides. Of the herbicides and rates tested, dicamba at a maximum of 4 pounds active ingredient per 100 gallons (1b aihg) (fig. 1) and bromacil at 12 1b applied as early foliar sprays were the most effective. The most effective concentration of picloram or dichlobenil was not attained in this study.

Figure 1.--Western swordfern plant killed by an early foliar spray of 3 pounds acid equivalent of dicamba per 100 gallons of water.

A second study was installed to find the minimum effective concentration of dicamba and bromacil. During May 1972, 10 individual western swordfern plants were sprayed to drip point with each treatment when new fronds were at the early- to late-hook stage. Most sprays were applied in water carriers. However, old fronds are also present at this stage, and these seem more resistant than new fronds to herbicides applied in water carriers. Therefore, an oil-soluble dicamba formulation applied in a diesel oil carrier was also tested. Results observed in July 1973, 14 months after treatment, are shown in table 2.

All treatments reduced the vigor of surviving plants compared with untreated swordfern. Averaged over all dosages, bromacil produced better plant kill than dicamba. As shown in figure 2, the minimum effective concentration of both herbicides is approximately 3 1b aihg. However, dicamba is somewhat more effective than bromacil at this concentration. The results also suggest that the oil-soluble formulation of dicamba applied in diesel oil is better than the water-soluble formulation applied in water at equal concentrations--1 pound acid equivalent per 100 gallons (1b aehg).

Both the water-soluble and oil-soluble formulations of dicamba are registered for use as high volume ground-applied sprays on forest land; bromacil is not. Therefore, dicamba is preferred to bromacil as an early foliar application for control of western swordfern.

Dicamba and bromacil are soil- and foliage-active and may severely damage conifers, so sprays should be carefully applied on individual swordfern plants to avoid drift onto adjacent conifers. For site preparation, dicamba should be applied the year before planting.

WESTERN BRACKEN

During the 1970 growing season, the four herbicides tested on western swordfern were also applied as foliage sprays on western bracken near Blodgett, Oregon. Each treatment was applied by knapsack sprayer in a water carrier at a volume equivalent to 200 gallons per acre to ten 1/1,000-acre circular plots. Herbicides were tested as early foliar sprays on June 15, when fronds were almost fully expanded, and as midsummer sprays on August 10, when fronds were mature and sori were green.

Table 2--*Effects of various concentrations of dicamba and bromacil as early foliar sprays on western swordfern, 14 months after treatment*

Herbicide and carrier	Concentration	Plants killed	No. of fronds per live plant	Average frond height
	lb aihg[1/]	Percent		Inches
Untreated	0	0	50	36
Dicamba (oil)	1	10	16	20
(water)	1	0	34	29
(water)	2	40	14	21
(water)	3	90	6	22
Bromacil (water)	1	20	29	25
(water)	2	50	12	17
(water)	3	70	22	20
(water)	6	70	8	18

[1/] Pounds of active ingredient per 100 gallons of carrier.

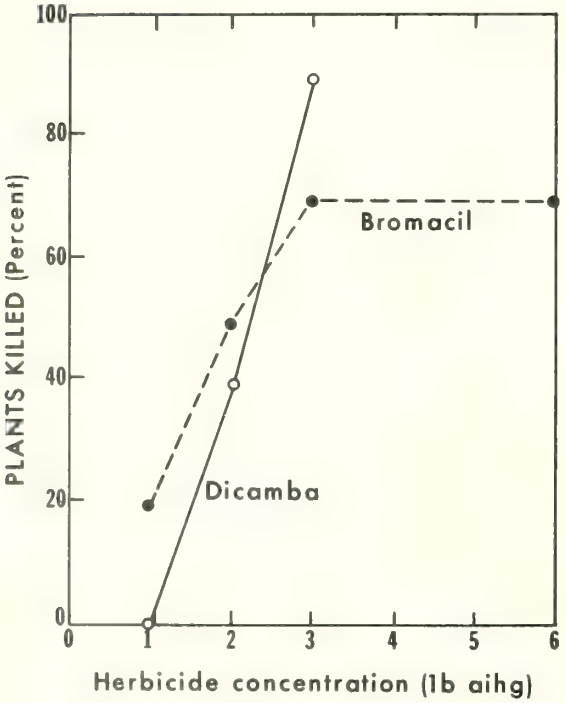

Figure 2.--Response of western swordfern to different concentrations of dicamba and bromacil.

During September 1971, 13 to 15 months after treatment, percent bracken cover and frond height and density were estimated on each plot. Height and density were obtained by measuring the average height and number of fronds in four systematically located 1-foot-square subsamples in each plot. The results of treatment are shown in table 3.

Dicamba was by far the most effective herbicide tested for reducing bracken cover, and 4 lb ai per acre was as effective as 8 lb. Early foliar sprays were less effective than midsummer sprays. This finding agrees with other studies, although Fechtig (1968) and Homesley and Furtick (1968) indicate that both picloram and dichlobenil can produce somewhat better control. Tests in Great Britain show that 4 lb ai per acre of dicamba can control bracken for up to four growing seasons on infertile sites but only for two seasons on fertile, moist sites (Forestry Commission 1969). In the present study, none of the

Table 3--*Effects of herbicides as early foliar or midsummer sprays on western bracken, 13 to 15 months after treatment*

Herbicide	Dosage	Early foliar spray			Midsummer spray		
		Cover	Stems	Average stem height	Cover	Stems	Average stem height
	lb ai/A[1/]	Percent	No./ft^2	Inches	Percent	No./ft^2	Inches
Untreated	0	87	1.8	43	87	1.8	43
Picloram	1	70	1.0	50	30	.9	43
	2	48	.9	49	16	.7	34
Dicamba	4	4	.5	43	24	.8	38
	8	2	.2	21	2	0	0
Dichlobenil	4	74	1.3	43	83	1.7	48
	8	86	1.6	48	90	1.5	47
Bromacil	12	76	1.6	46	60	1.2	53

[1/] Pounds of active ingredient per acre.

herbicides adequately controlled western bracken beyond the second season.

Dicamba is somewhat persistent, soil active, and can severely damage conifers (Ryker 1970, Stewart 1974). Asulam, a herbicide developed in Great Britain, has produced excellent control of other varieties of bracken fern at 4 to 8 lb ai per acre without damaging certain species of conifers (Holroyd et al. 1970, Martin et al. 1972, Soper 1972, Wasmuth 1973). Its effects on Douglas-fir (*Pseudotsuga menziesii*) and western bracken were unknown; therefore, a test was installed near Harlan, Oregon, to compare effectiveness of asulam and dicamba for control of western bracken.

Each treatment was applied to three 1/100-acre-square plots of western bracken in mid-July of 1972 after complete frond elongation. All sprays were applied with 0.2 percent surfactant in water at a volume equivalent to 200 gallons per acre. Bracken cover and stem density and height were observed in July--12, 24, and 36 months after treatment. Stem density and height were measured in five 1-foot-square subsamples systematically located along the diagonals in each plot. Results of the first and last examinations are shown in table 4. Change in bracken cover during the 3 years after treatment is shown in figure 3.

Asulam was more effective than dicamba in reducing bracken cover during the 3-year study. Effects of dicamba were evident by the end of the first growing season, 2 months after treatment. In contrast, asulam did not affect existing fronds but prevented emergence of new fronds the next year. Sprays containing 1 lb ai per acre of

Table 4--*Effect of dicamba and asulam as midsummer foliage sprays on western bracken*

Herbicide	Dosage	12 months after treatment			36 months after treatment		
		Cover	Stems	Average stem height	Cover	Stems	Average stem height
	lb ai/A[1/]	Percent	No./ft^2	Feet	Percent	No./ft^2	Feet
Untreated	0	90	1.33	5.1	88	1.07	4.7
Dicamba	4	57	1.20	2.4	73	1.20	4.0
Asulam	1	12	.13	2.6	27	.40	3.8
	2	8	.10	2.3	12	.08	2.1
	3	5	.03	2.0	7	.20	2.5

[1/] Pounds of active ingredient per acre.

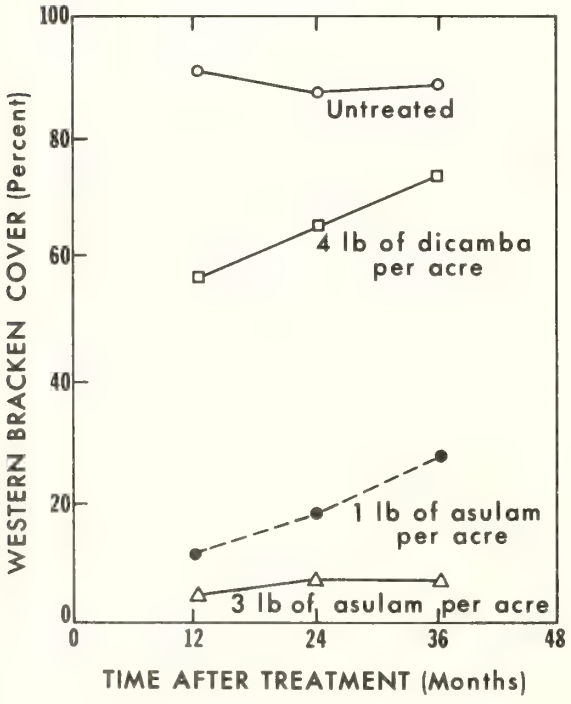

Figure 3.--Western bracken cover on untreated plots and on plots treated with dicamba or asulam.

asulam were almost as effective as sprays containing 2 or 3 lb. Bracken treated with dicamba recovered substantially by the 3d year after spraying (fig. 4). In contrast, recovery was very slow after treatment with asulam, even at the lowest dosage (fig. 5). As expected, Douglas-firs present on the plots at the time of treatments were severely damaged by dicamba (fig. 6); asulam did not damage trees at dosages up to 3 lb ai per acre (fig. 7).

Effectiveness of asulam for controlling western bracken was confirmed in a small test installed during June 1973 on the Entiat Ranger District of the Wenatchee National Forest in the Wenatchee Mountains of central Washington. Three 1/100-acre plots each were sprayed with 1 or 3 lb ai per acre of asulam with 0.2-percent surfactant in water at a carrier volume equivalent to 200 gallons per acre. Results obtained 12 months after treatment are shown in table 5.

As in tests in western Oregon, asulam produced good control of western bracken in central Washington. However, a higher

Figure 4.--Bracken fern recovered substantially by the 3d year after spraying with 4 lb aehg of dicamba.

Figure 5.--Bracken fern recovered very slowly after treatment with asulam.

Figure 6.--Dicamba severely damaged Douglas-firs such as this 3-foot-tall tree.

Figure 7.--Asulam did not damage Douglas-firs such as these two 3-foot-tall trees.

Table 5--*Effect of asulam applied as an early foliar spray on western bracken in the Wenatchee Mountains, 12 months after treatment.*

Treatment	Dosage	Cover	Stems	Stem height
	lb ai/A[1/]	Percent	No./ft^2	Feet
Untreated	0	53	1.53	1.8
Asulam	1	37	.60	1.2
	3	10	.07	1.8

[1/] Pounds of active ingredient per acre.

dosage was required to control the shorter, more open bracken on these sites than to control the taller, more dense bracken in western Oregon. Perhaps western bracken growing on drier sites is more resistant to asulam or may have a thicker waxy cuticle that reduces uptake of herbicides applied in water carriers.

To better determine the suitability of asulam for conifer release, 10 seedlings each of Douglas-fir and ponderosa pine (*Pinus ponderosa*) were sprayed to drip point with 1/2 lb aihg of asulam in a water carrier. Treatments were applied on June 19 at the beginning of active growth, on July 13 as terminal growth stopped but while new growth was succulent, and on August 14 after buds were set and new growth was woody. The concentration approximated a 2-lb-ai-per-acre application rate based on experience with phenoxy herbicides (Gratkowski 1961). Defoliation and topkill 2 years after spraying and average annual height growth before and after spraying are shown in table 6.

The data show that asulam did not affect height growth of either Douglas-fir or ponderosa pine after adjusting for differences in individual tree growth before treatment using covariance analysis. However, variation was considerable, and some small growth reduction may be possible.

Douglas-firs seemed more sensitive to asulam than ponderosa pines. Visible damage was slight in both species, but susceptibility was highest on June 19 during the period of active growth. This suggests that Douglas-fir and ponderosa pine seedlings can be safely released if sprays are applied after new growth ceases and terminal buds have set. This conclusion has been verified in a series of aerial spray tests.[1]

CONCLUSIONS

Western swordfern can be adequately controlled with sprays containing 3 lb aehg of dicamba applied in water to drip point on individual plants. Sprays can be applied anytime between the midhook and fully elongated frond stages, approximately mid-May to late July. Damage to conifers can be prevented if sprays are applied the year before planting or carefully directed away from young conifers on the site.

Western bracken can be controlled for at least 3 years with 1 to 3 lb ai per

[1]Unpublished data on file at the Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oreg.

Table 6--*Effect of asulam on Douglas-fir and ponderosa pine seedlings 2 years after treatment*

Species and application date	Initial height	Average annual height growth		Defoliation	Topkill
		Before treatment 1/	After treatment 2/		
	- - - - - - Meters - - - - - -			Percent	
Douglas-fir:					
Untreated	1.68	0.55	0.73	0	0
June 19	1.64	.44	.59	12	3
July 13	1.78	.58	.73	2	0
August 14	1.73	.56	.60	10	0
Ponderosa pine:					
Untreated	1.73	.59	.98	5	0
June 19	2.03	.58	.86	14	0
July 13	1.72	.64	.87	5	0
August 14	1.96	.74	.91	5	0

1/ Total growth during the 2 years before treatment.
2/ Total growth during the 2 years after treatment.

acre of asulam applied after frond emergence, but some recovery of bracken may occur after treatment with 1 lb of asulam. Sprays applied in mid-July or August produced good bracken control without damaging Douglas-firs or ponderosa pines. Asulam is registered for use on Christmas tree plantations, and registration for use in site preparation and conifer release on forest lands is expected soon.

Experience suggests that results from small plot tests such as those reported here often closely agree with results from operational use under similar conditions. However, as with any new technology, it is wise to begin use of new herbicides on a small scale to establish local experience. This preliminary step can save time and money later. Further, sharing your experience with others can prevent adoption of faulty technology and hasten adoption of useful technology.

METRIC CONVERSIONS

1 pound = 0.45 kilogram
1 inch = 2.54 centimeters
1 gallon = 3.78 liters
1 acre = 0.40 hectare
1 foot = 0.30 meter

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PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key--out of the reach of children and animals--and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

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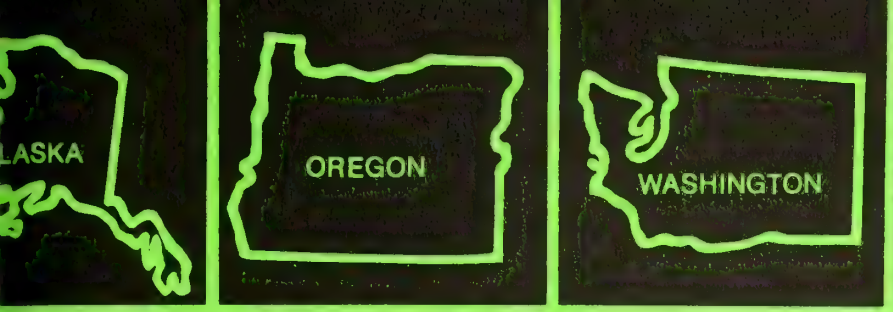

PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

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December 1976

HERBICIDES FOR GRASS AND FORB CONTROL IN DOUGLAS-FIR PLANTATIONS

by

H. Gratkowski, *Research Forester*

ABSTRACT

Tests of 10 chemicals were conducted to determine their relative effectiveness for grass and forb control in Douglas-fir plantations. Atrazine at 4 lb ai per acre and terbacil at 2 lb ai per acre should be useful in broadcast or aerial sprays to release small Douglas-firs. Atrazine reduced grass cover for 1 year, but had little effect on broadleaved weeds. Terbacil reduced both grass and forbs through two summers after application. Dalapon and a granular formulation of dichlobenil damaged the conifers but should be useful for site preparation in grass-forb communities.

KEYWORDS: Herbicides, grass control, forb control, release, spraying (aerial), herbicide preparations.

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

Dense stands of grasses and broadleaved weeds prevent establishment and retard growth of Douglas-fir seedlings on forest land in western Oregon and Washington. Shading and matting by weeds and grasses reduce survival and growth of small trees in dense grass-forb communities; however, root competition for limited soil moisture during the dry summer season is probably far more important.

Late winter aerial application of 4 lb ai (active ingredient) of atrazine per acre has proved effective in controlling most grasses but is relatively ineffective against many broadleaved weeds. As a result, atrazine releases not only conifers but forbs as well. Fast-growing forbs then multiply and dominate the site, shading the trees, using valuable soil moisture, and smothering small trees under a mat of dead stems and leaves when the weeds die during summer and autumn. Foresters need a broad-spectrum herbicide that will control most species of grasses and broadleaf weeds without damaging young conifers.

HERBICIDES[1/] AND METHODS

Ten herbicides (table 1) were tested in southwestern Oregon for grass and broadleaf weed control in three plantations of established young Douglas-firs 6 to 15 inches tall. Two study areas were on wet sites in the Siskiyou National Forest: one on the coastal slope of the Siskiyou Mountains near Brookings; one near the crest of the Coast Range west of Powers. The third area was in a Bureau of Land Management plantation on a dry site in the foothills of the Cascade Range east of Roseburg. Two additional replications (without conifers) were also installed on a very dry site in the Rogue River Valley west of Grants Pass.

Different rates of herbicides and combinations of herbicides provided 22 treatments on each site. All herbicides were applied on 1/100th-acre plots, and each replication contained one untreated plot for comparison. The screening test was installed as a randomized complete block experiment with one block of treatments on each of the five sites. Most of the chemicals are soil-active herbicides absorbed through roots of susceptible species. Therefore, all plots were sprayed between March 7 and April 18, 1969, when sufficient rainfall could be expected after application to leach the chemicals into the soil.

All chemicals except 2,4-D were applied as the active ingredient listed in table 1; 2,4-D was a low volatile ester formulation. All chemicals were applied in water carriers at a rate of 100 gallons of spray per acre. The wettable powder formulation of dichlobenil was included on all five sites, but a 4 percent active ingredient granular form of dichlobenil arrived late and was only included in the Brookings, Powers, and Roseburg replications.

Degree of grass control and effects of the herbicides on broadleaf weeds and young Douglas-firs were observed on three dates. A late June 1969 examination was made to detect effects of the herbicides on annual grasses and broadleaf weeds that would die naturally during summer. This examination provided a basis for evaluating results of a second examination in September 1969 which measured grass and weed control at the end of the first growing season. The third examination in September 1970 determined whether any herbicides showed residual effects indicated by second year mortality of grasses or broadleaved weeds or delayed reinvasion of the sprayed plots.

[1/] Use of trade, firm or corporation names is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be equally suitable.

Table 1--*Chemicals tested for grass and forb control in young Douglas-fir plantations in Southwestern Oregon*

Common name	Chemical name	Formulation
ACP 68-72	pyrido(3,2-d)pyrimidine-2,4(H,3H)-dione, 3-sec butyl.	Wettable powder
atrazine	2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine	Wettable powder
cacodylic acid	hydroxydimethylarsine oxide	Liquid
chlorthiamid	2,6-dichlorothiobenzamide	Granular powder
dalapon	2,2-dichloropropionic acid	Soluble powder
dichlobenil	2,6-dichlorobenzonitrile	Granular (4% ai)
dichlobenil	2,6-dichlorobenzonitrile	Wettable powder (50% ai)
2,4-D	(2,4-dichlorophenoxy)acetic acid	Liquid
propazine	2-chloro-4,6 bis(isopropylamino)-s-triazine	Wettable powder
terbacil	3-tert-butyl-5-chloro-6-methyluracil	Soluble powder

During each examination, an ocular rating was made of percentage reduction in grass and broadleaved weed cover on treated plots as compared to an untreated control plot and adjacent areas outside the spray plots. Effects of the herbicides were also observed on 15 young Douglas-firs, five on each plot in the three replications stocked with Douglas-fir seedlings. For each tree, notes were taken on whether the tree was dead or alive. If alive, an estimate was made of percentage of crown defoliated, damaged, and killed.

RESULTS

Both grass control and broadleaf weed control varied among chemicals and with rates of application. Generally, first-year control was better than that achieved with residues that remained in the soil the second summer after application.

Grass Control

By far the most effective chemicals at the end of the first summer were **terbacil**, **atrazine**, and **dalapon** in that order (table 2). Terbacil at 2 and 3 lb active ingredient per acre provided excellent grass control for two growing seasons after application. In contrast, atrazine allowed a rapid recovery of grasses when fall rains began at the end of the first summer and had little or no residual effect the following year. Adding small amounts of either 2,4-D or cacodylic acid and 2,4-D to atrazine seems inadvisable; they had little effect on grasses and did not appreciably increase broadleaf weed control.

Dalapon at 6.8 and 13.6 lb ai per acre produced acceptable grass control the first summer, but residues in the soil had much less effect on grasses the second summer after application.

Table 2--*First- and second-year control of grasses and forbs following chemical treatment during March-April 1969*

Treatments			Grass control		Forb control	
Chemicals	lb/acre[1/]	Carrier	Autumn 1969	Autumn 1970	Autumn 1969	Autumn 1970
			Percent killed			
atrazine	3 ai	Water	63	8	14	2
atrazine	4 ai	Water	85	10	34	2
atrazine + 2,4-D	3 ai 1/2 ae	Water	70	5	27	13
atrazine + cacodylic acid + 2,4-D	3 ai 1/2 ae 1/2 ae	Water	70	6	26	4
ACP 68-72	2 ai	Water	21	29	13	17
ACP 68-72	4 ai	Water	55	46	28	33
ACP 68-72	6 ai	Water	48	5	18	2
terbacil	1 ai	Water	75	42	52	11
terbacil	2 ai	Water	88	74	62	51
terbacil	3 ai	Water	85	87	59	63
dalapon	6.8 ai	Water	69	21	11	28
dalapon	13.6 ai	Water	80	28	8	7
chlorthiamid	2 ai	None	24	1	3	0
chlorthiamid	4 ai	None	45	30	23	13
chlorthiamid	6 ai	None	67	33	36	29
propazine	4 ai	Water	57	11	14	8
dichlobenil WP[2/]	2 ai	Water	9	12	6	4
dichlobenil WP	4 ai	Water	14	7	3	4
dichlobenil WP	6 ai	Water	56	24	27	9
dichlobenil G4[3/]	2 ai	None	30	12	12	15
dichlobenil G4	4 ai	None	60	50	28	22
dichlobenil G4	6 ai	None	65	52	40	15

1/ Pounds active ingredient (ai) or acid equivalent (ae).

2/ Wettable powder.

3/ Granular.

Granular **dichlobenil** was far more effective than the wettable powder formulation. Although first-year grass control was less than that of terbacil, atrazine, and dalapon, both the 4 and 6 lb per acre rates of granular dichlobenil appreciably reduced grass cover for two summers after application. Residual effects, the second summer, however, were not as great as those of terbacil.

Chlorthiamid was not quite as effective as equal rates of granular dichlobenil. This is not surprising, since chlorthiamid is converted to dichlobenil in soils (Benyon and Wright 1972), and grass control is probably achieved as dichlobenil rather than as chlorthiamid. Undoubtedly, some chlorthiamid is lost or degraded during conversion to dichlobenil in the soil, leaving less of the active ingredient to act on the grasses and broadleaf weeds.

ACP 68-72 was less effective than the chemicals described above, although it did have some residual effect the second summer after application. Development of this chemical has been discontinued by the manufacturer.

Propazine was less effective than an equal amount of atrazine per acre. Grass control with propazine was appreciably less than that obtained with atrazine the first summer after application, and residual effects on grasses the second summer were not great enough to be of practical value. Broadleaf weed control was no better than that obtained with atrazine.

Broadleaf Weed Control

Terbacil, **granular dichlobenil**, and **chlorthiamid** were the only chemicals that produced potentially useful reductions in forb cover. Of these, only terbacil residues produced a significant

reduction the second summer after application. Terbacil is considered the only promising chemical for use where 2-year control of competitive vegetation is desired in grass-forb communities. Until registered, however, terbacil cannot be used for this purpose on forest land.

Conifer Damage

Only **atrazine** and **terbacil** appear useful for releasing young Douglas-firs from grasses (table 3). Although the data show some damage to Douglas-fir from the 3 lb per acre rate of atrazine, most of this occurred on one tree on a dry interior valley plot. Trees sprayed with atrazine at a higher rate of 4 lb ai per acre and those treated with all rates of terbacil appeared normal, healthy, and undamaged at the end of the second summer following spraying. Newton (1969) stated that adding 2,4-D plus cacodylic acid to atrazine proved especially effective in releasing young Douglas-firs from grasses and broadleaved weeds. Adding small amounts of 2,4-D or 2,4-D plus cacodylic acid to atrazine did not damage the young firs in these tests, but their failure to appreciably increase broadleaf weed control does not seem to justify the increased expense.

Although both atrazine and terbacil should be useful for conifer release in grass-forb communities, only atrazine is registered for conifer release in western Oregon and Washington; terbacil is not. Atrazine may be used only in combination with dalapon east of the Cascade Range. Terbacil is not registered for use on forest land.

Table 3--*Young Douglas-firs killed or damaged and degree of damage sustained by the injured trees sprayed with herbicidal chemicals during March-April, 1969*

Treatment		1969					1970			
Chemical	lb/acre[1/]	Sprayed trees			Damaged trees		Sprayed trees		Damaged trees	
		Examined	Dead	Damaged	Defoliation	Crown kill	Dead	Damaged	Defoliation	Crown kill
		Number			Percent[2/]		Number		Percent[2/]	
atrazine	3	15	0	3	13	0	1	4	44	25
atrazine	4	14	0	1	20	0	0	0	0	0
atrazine D	3+1/2	15	0	1	5	0	0	1	5	4
atrazine CD	3+1/2+1/2	15	0	4	10	2	0	0	0	0
ACP 68-72	2	15	0	5	19	0	0	0	0	0
ACP 68-72	4	15	2	7	50	44	2	4	59	50
ACP 68-72	6	15	1	8	24	14	1	4	52	36
terbacil	1	15	0	2	27	2	0	1	1	1
terbacil	2	15	0	2	12	6	0	0	0	0
terbacil	3	15	0	4	10	18	0	0	0	0
dalapon	6.8	15	0	6	12	0	0	3	30	7
dalapon	13.6	15	0	9	34	4	0	7	25	7
chlorthiamid	2	15	0	3	30	0	0	2	35	2
chlorthiamid	4	15	0	3	8	3	0	1	10	2
chlorthiamid	6	15	0	0	0	0	0	0	0	0
propazine	4	15	0	0	0	0	0	1	15	0
dichlobenil WP	2	15	0	4	10	0	0	3	22	2
dichlobenil WP	4	15	0	5	11	0	1	3	52	33
dichlobenil WP	6	15	1	5	34	21	0	0	0	0
dichlobenil G4	2	15	0	3	13	0	0	2	33	5
dichlobenil G4	4	15	0	1	15	5	0	0	0	0
dichlobenil G4	6	15	0	4	30	1	0	2	17	1

1/ Active ingredient or acid equivalent as shown in table 2.
2/ Average defoliation and crown kill on the damaged trees.

Both **dalapon** and **ACP 68-72** damaged young Douglas-firs when applied as foliage sprays in these tests. Dalapon seems more suitable for site preparation rather than in broadcast sprays to release young conifers. Dalapon is the only chemical now registered for use east of the Cascade Range, where it may be used for site preparation (Stewart and Beebe 1974) or as a directed spray in combination with atrazine to release conifers in Oregon, Washington, and Idaho. Interim State registrations permit broadcast and aerial application of Dowpon® M plus atrazine mixtures as foliage sprays only west of the crest of the Cascade Range in Oregon and Washington.

This registered combination of dalapon and atrazine has proved useful in western Oregon and Washington. Newton and Overton (1973) reported that foliage sprays of dalapon injured young Douglas-firs and grand firs (*Abies grandis* (Dougl.) Lindl.). Dalapon, however, at rates of 4 to 12 lb per acre did not injure the trees when combined with atrazine and low volatile esters of 2,4-D at rates of 3 and 4 lb per acre, respectively. Newton recently indicated that use of cacodylic acid is no longer recommended in herbicidal mixtures to be applied as foliage sprays on young conifers; rates $\geq$ 1 lb per acre injure the trees[2/].

Dichlobenil and **chlorthiamid** caused some second-year defoliation of Douglas-fir seedlings. Considering its greater effect on broadleaf weeds and 2-year control of grasses, however, granular dichlobenil may prove a useful chemical for site preparation on sites occupied by mixed stands of grasses and broadleaf weeds. In England, a granular formulation of chlorthiamid is registered for release of trees from grasses and forbs, although Allen (1966) reported injury and mortality in conifers treated with 5 to 8 lb ai of chlorthiamid per acre. Chlorthiamid is not registered for forest use in the United States.

SUMMARY

Atrazine and **terbacil** proved the most useful chemicals for grass control and conifer release in these tests. Foliage sprays of both chemicals controlled grasses without permanent damage to Douglas-fir seedlings. For many years, atrazine at 4 lb ai per acre has proved effective in releasing young conifers from grasses without damaging the trees, but it is effective for only one summer and does not control broadleaf weeds. Terbacil at 2 lb ai per acre appears promising as an alternative. Although this chemical damaged a few firs during the first summer after spraying, no trees were killed and all were healthy and vigorous at the end of the second summer.

Granular dichlobenil at 4 to 6 lb ai per acre also controlled grasses and forbs for two summers but produced persistent damage on young Douglas-firs. Dichlobenil seems potentially more useful for site preparation than for conifer release on sites occupied by grasses and broadleaf weeds. Because of persistent damage through the second summer, reforestation would probably have to be delayed until at least three summers elapse after application. By that time, however, grass and broadleaf weed control may not be sufficient to favor the conifers; benefits may not warrant the expenditure.

[2/] Personal communication, August 1976.

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PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key--out of reach of children and animals--and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

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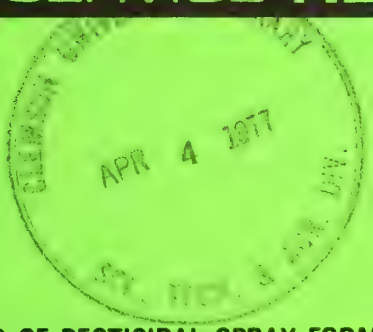

PNW-286 January 1977

SPREAD FACTORS OF PESTICIDAL SPRAY FORMULATIONS ON KROMEKOTE CARDS

by

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ABSTRACT

To determine spherical drop size from a known spot size on a particular sampling surface it is necessary to know the spread factor for drops of pesticidal formulations. A vibrating reed apparatus is an excellent droplet generator for oil-base formulations. Magnesium oxide coated slides were used as a reference surface to determine spread factors for Kromekote cards. Uniform size droplets were collected by the two sampling surfaces and spread factor estimates were made from their ratios. Spots are made visible by use of dyes such as Brilliant Sulpho Flavine FFA, Rhodamine B, Nigrosine, and Sudan Deep Black. Spread factors for approximately 60 formulations are summarized. Several problems related to spread factor determination are discussed.

Keywords: Pesticide application methods, spraying (aerial), pesticide preparations.

REST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

INTRODUCTION

To understand the effects of aerial application of pesticides, it is important to determine relationships between target effect and spray factors such as drop density, atomization, and gallons per acre. Spray deposit assessment is the key to the determination of these factors.

As the latter two factors require actual drop diameters, we must employ a corrective spread factor to the stain marks on our sampling surface to find the actual drop size. This conversion or spread factor is the ratio of the diameter of the stain to the diameter of the drop causing it.

The determination of a particular spread factor involves the production, collection, and measurement of groups of uniform size droplets from which a calibration curve can be made.

This paper summarizes the spread factor determination on white paper Kromekote cards for various pesticidal formulations.

MATERIALS AND METHODS

Uniform spherical droplets were produced by means of a vibrating reed apparatus (fig. 1) similar to that described by Davis (1951) and Maksymiuk and Moore (1962). The reed, which bore a needle affixed at the end, was vibrated at resonance to produce maximum amplitude. As the needle passed through the liquid emanating from a hypodermic syringe, streams of droplets were formed (fig. 2).

Figure 1.--Droplets produced by vibrating reed droplet generator are caught on sampling tray.

Figure 2.--Two streams of uniform size droplets are produced by the vibrating reed.

A water manometer was used to provide a constant flow of liquid from the syringe. Back lighting provided easy viewing of the stream of droplets. Uniform size droplets, 50 to 500 micrometers (μm) in diameter, were produced by varying the amplitude of the reed vibration, needle size, flow rate, and reed position in the liquid emanating from the syringe.

Dyes were added to the spray formulation to make the spots visible. Mainly fluorescent dyes were used, such as Brilliant Sulpho Flavine FFA (BSF) and Rhodamine B extra S which are water soluble, and Rhodamine B extra base, an oil-soluble dye. Nonfluorescent dyes, Nigrosine, a black water-soluble dye, and Sudan Deep Black, an oil-soluble dye, were also used occasionally. The dye concentration was 0.1 gm per 100 ml (0.1 percent W/V) in all the spray formulations except as noted in the tables. All of the dyes mentioned here are manufactured by General Dyestuff Division, General Aniline and Film Corp. (GAF), 435 Hudson Street, New York 14, N. Y.[1/]

Spread factor was determined by passing cards and magnesium oxide (MgO) coated slides through a stream of uniform droplets produced by the vibrating reed apparatus and then performing the necessary measurements and calculations. The spherical drop diameter is the diameter of the crater formed by the droplet penetrating the MgO coating multiplied by a conversion factor of 0.86. According to May (1950) this conversion factor varies slightly with droplet size. The thickness of the MgO coating must be at least the diameter of the impinging drops. The slides and cards are viewed with a binocular microscope with a reticle containing a calibrated scale inserted in one of the oculars. With transmitted light, the inside diameters of the craters are readily visible and easily measured (in our case to the nearest 50 μm). Depending on the dye used, the spots on cards are viewed with reflected white or ultraviolet light and their outside diameters measured to the nearest 50 μm. Before measuring, sufficient time must be allowed for the spots to cease spreading. The time needed will depend on the type of formulation. Water-base formulations reach their maximum spread in less than 1 hour, whereas oil-base formulations will continue to spread for several hours.

Variation is minimized by using the mean of 10 spots or drops from each card and its corresponding slide. These values are used in the following formula for the spread factor determination of that drop size:

$$\text{spread factor} = \frac{\text{outside spot diameter on card}}{\text{inside MgO crater diameter} \times 0.86} .$$

To account for the variation of spread factor with drop size, the spread factor must be determined for the working range of drop sizes. Maksymiuk and Moore (1962) found that the relationship between the drop diameter and spot diameter for fuel oil number 2 was linear for drops larger than 125 μm. A linear regression equation can, therefore, be conveniently used to convert spot diameters to drop diameters.

[1/] The mention of products and companies by name does not constitute endorsement by the USDA, nor does it imply approval of a product to the exclusion of others which may also be suitable.

RESULTS AND DISCUSSION

The first table is concerned with microbial insecticidal formulations for *Bacillus thuringiensis* (Dipel and Thuricide) and the Douglas-fir tussock moth nucleopolyhedrosis virus (NPV). These are all water-base formulations and have spread factors in the vicinity of 2.00. Two formulations were filtered, and one was decanted because the complete formulation would not flow through the syringe needle. The data obtained for these three should not be construed as representing the complete formulation.

Table 1--*Spread factor and linear relationship between spot (y) and drop (x) diameter for microbial insecticides on Kromekote cards*

Formulation	Dye[1/]	Mean spread factor	Range (spherical drop diameter μm)	Linear regression equation	Correlation coefficient
1/2 lb Dipel WP in 25% CIB (cargill insecticide base-molasses) and H_2O to make 1 gal (filtered)	Rhod B S	1.82	80-400	Y=2.02X-34.37	0.9970
1 lb Dipel WP in 25% CIB, and H_2O to make 1 gal (filtered)	Rhod B S	1.81	112-425	Y=2.22X-87.00	.9900
1/2 lb Dipel WP in 25% CIB, 3.2% Maywood formula, and H_2O to make 1 gal	BSF	2.42	86-387	Y=2.02X+77.26	.9832
1/2 lb Dipel WP in 25% CIB, 3.2% Maywood formula, 3% Chevron sticker, and H_2O to make 1 gal (decanted)	BSF	2.65	67-344	Y=2.35X+46.59	.9873
50% Dipel LC, 50% H_2O	Rhod B S	1.95	100-325	Y=1.93X+2.77	.9808
67% Dipel LC, 33% H_2O	Rhod B S	1.77	112-475	Y=2.35X-140.86	.9749
1/2 lb Dipel WP + 25% Sorbo and H_2O to make 1 gal	Rhod B S	1.69	64-592	Y=1.83X-19.32	.9950
1/2 lb Dipel WP + 25% Sorbo + 5% w/v Shade + H_2O to make 1 gal	Rhod B S	1.56	64-688	Y=2.00X-81.12	.9897
1 lb Dipel WP in 12.5% Biofilm, + H_2O to make 1 gal	BSF	2.79	86-344	Y=2.69X+23.21	.9762
1 lb Dipel, 0.125% Biofilm	Rhod B S	1.74	75-550	Y=2.04X-48.70	.9973[2/]
25% Thuricide HPC, 25% CIB, 3% sticker, and 47% H_2O	BSF BSF	2.24 2.06	92-516 92-516	Y=2.40X-31.45 Y=2.29X-42.78	.9560 .9590[3/]
50% Thuricide 16B, 50% H_2O	Rhod B S	1.88	87-525	Y=1.87X+1.30	.9976
25% Thuricide 16B, 75% H_2O	Rhod B S	1.94	100-300	Y=1.91X+5.45	.9951
50% Thuricide 16B, 0.2% w/v $FeCl_3$ and H_2O to make 1 gal	No dye	2.13	97-548	Y=2.04X+16.24	.9816
33% Thuricide 24B, 67% H_2O	Rhod B S	2.17	86-387	Y=2.32X-28.58	.9910
25% Thuricide 32B, 50% H_2O, 25% Sorbo	Rhod B S	1.64	86-333	Y=1.80X-24.69	.9944
50% Sandoz V[5/], 50% H_2O[4/]	No dye	1.62	129-280	Y=1.87X-46.85	.9652
25% CIB, 75% H_2O[4/]	BSF	1.99	43-430	Y=1.57X+61.85	.9848
25% CIB, 0.5 lb/gal Shade + H_2O to make 1 gal[4/]	BSF	1.94	70-323	Y=2.00X-10.15	.9769

1/ Rhod B S is Rhodamine B extra S and BSF is Brilliant Sulpho Flavine FFA.

2/ Printflex cards.

3/ Kromekote cards with glossy coat on one side.

4/ Carrier for nucleopolyhedrosis virus (NPV) formulation for Douglas-fir tussock moth.

5/ An aerial adjunct for virus formulation from Sandoz Co.

Table 2 depicts a variety of oil- and water-base chemical insecticidal formulations; the variation of spread factor according to the formulation of a particular insecticide is of special interest. Several insecticidal carriers are also included in table 2.

Table 2--*Spread factor and linear relationship between spot (y) and drop (x) diameter for chemical insecticides on Kromekote cards*

Formulation	Dye[1/]	Mean spread factor	Range (spherical drop diameter μm)	Linear regression equation	Correlation coefficient
Oil base					
0.01 lb/gal Bioethanomethrin, 1% Wingstay 100[2/] in Klearol to make 1 gal	Rhod B	4.30	86-344	Y=4.57X-46.38	0.9789
0.01 lb/gal Bioethanomethrin, 1% Wingstay 100[2/] in Panasol to make 1 gal	Rhod B	5.70	86-237	Y=6.06X-51.34	.9519
0.1 lb/gal Pyrethrins, 5.6% Dowanol DB, 89.2% heavy mineral oil, 3.6% stabilizers	Oil red O Oil red O	6.06 5.64	129-430 129-430	Y=6.74X-139.82 Y=6.53X-183.20	.9994 .9956[3/]
67% Dylox 1.5, 33% Orchex 796	Rhod B	2.20	129-688	Y=2.13X+9.66	.9948
Dylox 1.5 oil undiluted	Rhod B	2.31	64-344	Y=1.91X+70.48	.9847
Dylox 4 undiluted	Rhod B	3.91	108-688	Y=4.15X-37.52	.9976
Fuel oil #2	Rhod B	4.82	43-258	Y=5.26X-42.77	.9923
Sevin-4-oil undiluted	Rhod B	2.18	70-194	Y=2.07X+17.24	.9742
25% Sevin-4-oil, 75% fuel oil #2	Rhod B	4.09	76-344	Y=4.30X-42.56	.9941
67% Sevin-4-oil, 33% fuel oil #2	No dye No dye No dye	2.13 2.12 2.38	129-297 129-297 129-297	Y=2.47X-63.60 Y=2.37X-47.67 Y=2.40X-4.05	.9519 .9526[4/] .9513[5/]
50% Sevin-4-oil, 50% fuel oil #2	Rhod B	2.31	86-443	Y=2.40X-20.59	.9945
10% Sumithion, 20% Panasol, 70% fuel oil #2	Rhod B	4.32	86-312	Y=5.60X-235.78	.9915
Dowanol TPM (carrier for Zectran)	Sudan Deep Black	4.93	43-301	Y=5.46X-60.74	.9905[3/]
Dowanol TPM (carrier for Zectran)	No dye	7.69	65-387	Y=9.45X-202.49	.9944[4/]
10% Zectran FS 1.5, 90% fuel oil #2	Rhod B Rhod B	4.87 4.86	65-473 65-473	Y=5.60X-107.71 Y=4.90X-70.58	.9901 .9893[3/]
10% Zectran FS 1.5, 90% Chevron C	Rhod B	3.99	75-430	Y=4.86X-123.12	.9957[3/]
Water base					
0.25 lb Dimilin 25% WP + H_2O to make 1 gal	Nigrosine	1.99	194-441	Y=1.89X+30.99	.9737
0.5 lb Dimilin 25% WP + H_2O to make 1 gal	Nigrosine	1.81	129-473	Y=1.70X+29.84	.9865
1 lb Dimilin 25% WP + H_2O to make 1 gal	Nigrosine	2.14	86-602	Y=2.32X-44.24	.9971
1 lb Dimilin 25% WP, 10% Ethylene glycol, in H_2O to make 1 gal	Rhod B S	2.18	86-430	Y=2.28X-16.46	.9971
Imidan IE undiluted	Rhod B	4.57	129-322	Y=4.77X-23.79	.9991
75% Imidan IE, 25% H_2O	Rhod B	3.97	97-473	Y=5.15X-204.72	.9995
50% Imidan IE, 50% H_2O	Rhod B	4.90	86-280	Y=4.37X+95.37	.9918
1 lb Orthene 75SP in H_2O to make 1 gal	Nigrosine	2.18	43-494	Y=2.41X-49.44	.9880
1 lb Orthene 75SP, 10% Ethylene glycol in H_2O to make 1 gal	Rhod B S	1.75	86-860	Y=1.89X-38.09	.9992
1 lb Orthene 75SP, 0.1% w/v $FeCl_3$ in H_2O to make 1 gal	No dye	2.06	86-387	Y=2.22X-33.39	.9788

1/ Rhod B is Rhodamine B extra base.
2/ Manufactured by B. F. Goodrich Co.
3/ Kromekote cards with glossy coat on one side.
4/ Red-dyed Kromekote.
5/ Blue-dyed Kromekote.

The first part of table 3 indicates that the type or concentration of dye may make a difference in the spread factor. When distilled water was used as a solvent, spread factor differences up to 17 percent were found for different dyes (0.5 percent Nigrosine vs. 0.5 percent Calcofluor) and up to 11 percent for different concentrations (0.1 percent Nigrosine vs. 0.5 percent Nigrosine). Adding a wetting agent to water greatly increased the spread factor (water + detergent + 0.1 percent Nigrosine vs. water + 0.1 percent Nigrosine). The spread factors of a few fertilizers and herbicides are shown at the bottom of the table.

Table 3--*Spread factor and linear relationship between spot (y) and drop (x) diameter for water, herbicides and fertilizers on Kromekote cards*

Formulation	Dye	Mean spread factor	Range (spherical drop diameter μm)	Linear regression equation	Correlation coefficient
Water					
Distilled water + detergent	0.1% Nigrosine	2.77	75-344	Y=2.89X-18.17	0.9779
Distilled water	.1% BSF	1.85	32-387	Y=1.76X+10.91	.9958
Distilled water	.1% Rhod B S	1.72	75-602	Y=1.81X-19.32	.9951
Distilled water	.1% Nigrosine	1.63	100-500	Y=1.90X-57.99	.9896
Distilled water	.5% Nigrosine	1.82	129-430	Y=1.64X+38.72	.9715
Distilled water	.5% Calcofluor	2.18	118-366	Y=1.85X+67.14	.9324
Herbicides and Fertilizers					
1723.0 g nitrogen, and H_2O to make 1 liter	Nigrosine	2.71	65-409	Y=2.93X-31.35	.9866
422.6 g nitrogen, and H_2O to make 1 liter	Nigrosine	2.76	129-705	Y=2.67X+27.17	.9900
16.3 g 2,4,5-T, and H_2O to make 1 liter	Nigrosine	2.86	27-2000	Y=3.08X-37.78	.9993
2 lb Benlate, and H_2O to make 1 gal	Rhod B S	2.42	108-731	Y=2.70X-92.45	.9949

Several complicating factors are evident in spread factor determination. Halo effects around spots can be caused by the unequal spreading of different ingredients in certain formulations. They can also be formed if the sampling card is damp. Precautions should be taken to prevent dampening of cards. The exact conditions of dampness for a spread factor calibration cannot be matched in the laboratory.

Another problem is that of irregular spreading of certain formulations. The drop forms an irregular or noncircular shaped spot. These are measured by taking an average of the maximum and minimum dimensions.

Two problems occur with the vibrating reed droplet generator due to the type of formulation used. First, water-base formulations differ from the oil-base formulations in that they do not generally form the two streams of uniform size droplets as the vibrating reed removes liquid from the syringe. Often it is very difficult to isolate streams of droplets of uniform size, and it becomes a matter of patience.

Second, some formulations contain particulates which settle and often plug the syringe needle. This problem can be minimized by providing constant agitation.

The tables show the linear regression equation for each formulation with the range of spherical droplet diameters which were measured to determine this equation. The experimental mean spread factor may be utilized as a close approximation

for calculations. The spread factor does not take into account, however, the variation of spread factor with droplet size. The correlation coefficient is greater than 0.95 in all cases except one, showing an excellent correlation between drop and spot size. Most of the work was done on white Kromekote paper--coated on both sides. A few other surfaces have been used such as Kromekote coated on one side, printflex, oil-sensitive red-dyed Kromekote (white Kromekote dipped in acetone with red dye), and blue-dyed Kromekote.

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METRIC CONVERSIONS

1 gallon =	3.785 liters
1 fluid ounce =	29.57 milliliters
1 pound =	453.59 grams
1 pound per gallon =	119.84 grams per liter

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

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BARK BEETLE RESPONSE TO CLEARCUT AND SHELTERWOOD SYSTEMS IN INTERIOR ALASKA AFTER WHOLE TREE LOGGING

by

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and

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ABSTRACT

Short-term response of bark beetles to clearcut and shelterwood silvicultural systems in interior Alaska was determined from a study of adult beetles trapped during flight. After logging, adult populations declined in clearcuts; adults increased dramatically the 1st year and declined the 2d year in the shelterwoods. The spruce beetle does not appear to be a major threat after whole tree logging under conditions of the study.

KEYWORDS: Bark beetles, Scolytidae, insect populations, shelterwood cutting method, clearcutting systems, Alaska.

[1/] Jerry O. Wolff is with the Museum of Vertebrate Zoology, University of California, Berkeley.

INTRODUCTION

Logging in the spruce forests of the Alaskan taiga will increase as the State's economy develops. Much of the logging will occur in areas not previously exposed to man's perturbations. The effects of logging activities on the residual stands should be considered by land managers in order to prevent unnecessary losses caused by insects.

Bark beetles are potentially the most destructive insect enemies of white spruce (*Picea glauca* (Moench) Voss) in interior Alaska. Beckwith (1972a) found 17 species of scolytids associated with white spruce in Alaska. Many of these species are secondary, attacking only dead or dying material. The spruce beetle, *Dendroctonus rufipennis* (Kirby), however, has killed white spruce over large acreages (Downing 1957, Baker and Kemperman 1974). *Ips* beetles are ubiquitous, causing losses whenever there is stand disturbance such as snow breakage, inundation, construction activity, or logging. The ambrosia beetle, *Trypodendron lineatum* (Oliv.), often increases after logging and causes reductions in grades of finished materials.

The causes of population fluctuations may vary with species, but availability of suitable breeding material is prerequisite to population increase. Many scolytids prefer recently killed or felled timber and slash to standing trees (Dyer and Chapman 1965, Dyer and Taylor 1968, Mason 1969, Sartwell 1970). Epidemic populations can arise in areas of excessive blowdown or slash accumulation after logging. Large populations of some species can successfully attack stands under physiological stress brought about by such things as overmaturity or adverse climatic conditions.

An increase in logging activity and the subsequent deposition of slash create increased breeding niches. The method of handling this material can influence future populations of bark beetles. This note reports the numerical response of bark beetles to clearcutting and shelterwood systems in interior Alaska after whole tree logging.

METHODS

The study was conducted within the silvicultural cutting areas at Bonanza Creek Experimental Forest located about 30 km (18.6 mi) southwest of Fairbanks, Alaska (Wolff and Zasada 1975) (fig. 1).

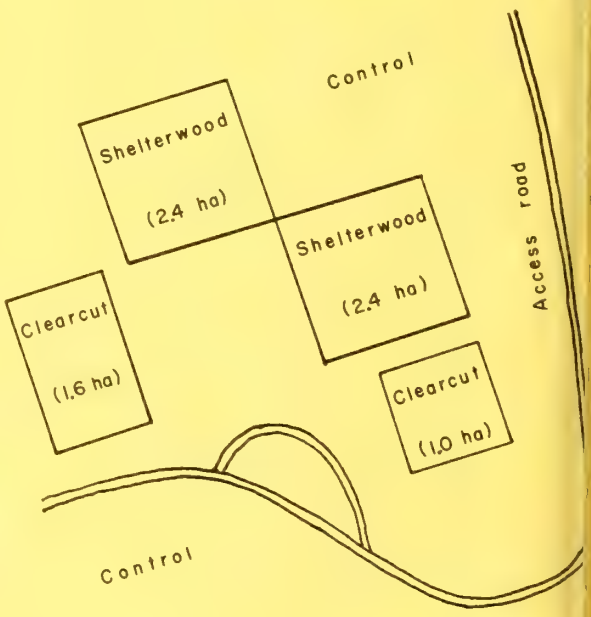

Figure 1.--Map of the cutting areas used in the bark beetle study, Bonanza Creek Experimental Forest, Alaska.

The area was logged in the fall of 1972 using whole tree logging, thus leaving little slash on the site (figs. 2 and 3). The trees were decked on site and removed in the spring of 1973. Most adult attack could not occur until 1973, since the areas were logged after the majority of beetle flights.

Study plots were established in two clearcuts, two shelterwoods, and two uncut (control) areas so we could observe population changes after logging. Adult bark beetle flight was monitored weekly from mid-May through early September by two large window flight

Figure 2.--General view of the clearcut area after whole tree logging.

Figure 3.--General view of the shelterwood area after whole tree logging. Number of trees in the stand was reduced by 78 percent.

traps (Chapman and Kinghorn 1955). The traps were established in 1972 one full season before logging. In addition, in 1973 10 small flight traps were placed directly on fresh stumps which were located uniformly throughout the cut areas. All flight traps were placed at right angles to prevailing winds. A screen emergence trap covering 600 cm^2 (93 in^2) was placed on each of 16 stumps in one shelterwood and in one clearcut plot during the summer of 1973 after major scolytid flight (Beckwith 1972b). These traps were moved to new positions in 1974. All scolytids from each trap and cage were placed in individual labeled vials in the field and separated by species at the laboratory.

RESULTS AND DISCUSSION

The response of bark beetle activity to cutting, as indicated by adult flight, is shown in figure 4. The apparent difference in the 1972 population between the clearcut, shelterwood, and uncut areas is most likely due to trap location in relation to population source rather than actual numerical difference in population between the areas. After logging, the shelterwood areas showed a 5.5-fold increase in 1973, followed by a decline in 1974; however, the 1974 population was about three times greater than before logging. This elevated activity in 1974 resulted primarily from infestations of the ambrosia beetle and *Ips* beetles in stumps and trees damaged during logging (table 1). A total of 28 and 17 standing trees died in the shelterwood areas during 1973 and 1974, respectively, as a result of logging damage followed by secondary bark beetle infestation, primarily by *Ips*.

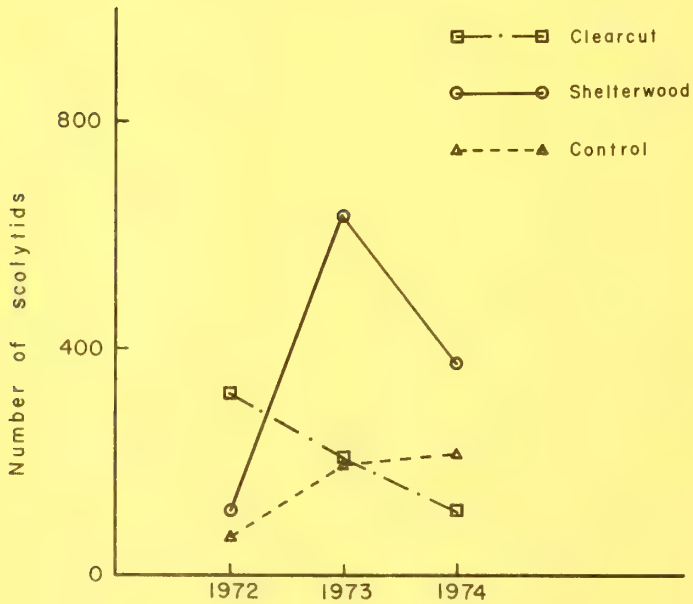

Figure 4.--Total number of scolytids from large flight traps, 1972-74. Values for 1972 are before logging; 1973 and 1974 are 1st and 2d years after logging.

A gradual decline in scolytid flight occurred in the clearcuts from 1972 to 1974. The decline could be accounted for by the removal of all the attractant source and/or changes in the microclimate to the extent that the areas were not favorable to adult flight. Also, increased solar radiation could cause a more rapid drying of the host material, making it less attractive to bark beetle infestation and/or survival. Beetle flight in control areas increased after cutting and remained approximately the same in 1974. Several large trees blew down in the control areas near the flight traps in 1973. These downed trees acted as an attractant source in 1973 and a population source in 1974. The importance of the proximity of susceptible host material to trap catch has been pointed out by other workers (Chapman and Kinghorn 1958, Hosking and Knight 1975).

Numbers of beetles caught in small flight traps located on the cut stumps followed the same general pattern as the catch in larger flight traps in 1973 and 1974 (table 1). The ambrosia beetle maintained relatively high activity in both the clearcut and shelterwood areas; however, the activity in the shelterwood was double that in the clearcut.

The weekly collections showed the same general species composition reported by Beckwith (1972b). Early

Table 1--*Scolytids collected from small flight traps 1 and 2 years after logging at Bonanza Creek Experimental Forest, Alaska*

Species	Treatment			
	Shelterwood		Clearcut	
	1973	1974	1973	1974
Dendroctonus rufipennis	166	14	39	7
Ips spp.	817	334	97	137
Trypodendron lineatum	1,976	1,889	890	711
Dryocoetes affaber	1,909	39	566	17
Polygraphus rufipennis	131	46	24	11
Miscellaneous	250	314	210	186
Total	5,249	2,636	1,826	1,069

flights in May and June represent the ambrosia beetle, the spruce beetle, and *Ips*; later summer activity is composed primarily of secondary scolytids such as *Polygraphus rufipennis* (Kby.) and *Dryocoetes affaber* (Mann.).

Emergence of bark beetles from the cut stumps was greater in the shelterwood areas than in the clearcut (table 2). Again, this difference was probably attributed to increased solar radiation in the clearcut causing warmer and drier stump conditions. *Trypodendron lineatum* was the principal emerging species, making up 93 percent and 95 percent of the 1973 total in the shelterwood and clearcut areas, respectively. The secondary bark beetle, *Dryocoetes affaber*, made up a greater percentage of the emergence from the stumps in the clearcuts in 1974. The spruce beetle was not an important component of the stump population based on the emergence cages.

Table 2--*Scolytids collected from stump emergence cages 1 and 2 years after logging at Bonanza Creek Experimental Forest, Alaska*

Species	Treatment			
	Shelterwood		Clearcut	
	1973	1974	1973	1974
Dendroctonus rufipennis	7	14	1	4
Ips spp.	28	--	2	--
Trypodendron lineatum	1,209	98	594	16
Dryocoetes affaber	55	61	19	19
Miscellaneous	7	7	10	2
Total	1,306	180	626	41

SUMMARY

Short-term response of bark beetles to the management practices and climatic conditions of the study varied with the treatment. Bark beetle populations in the clearcuts declined continuously after logging. Much of the decline could be attributed to the lack of an attractant source and to changes in the microclimate that made conditions unsuitable to population increase. The magnitude of numerical change in bark beetles was greatest in the shelterwoods, with a sharp rise after cutting followed by a decline. Most of the change was caused by an increase of ambrosia beetles in the cut stumps and the response of secondary bark beetles to stumps, logging slash, and damaged trees. Populations of the spruce beetle remained low; therefore, this species does not appear to be a major threat after whole tree logging in white spruce. The response of bark beetles in a shelterwood cutting would be expected to change with such things as age, structure, windthrow, or general climatic factors such as prolonged drought that would influence the general physiological condition of the residual trees.

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January 1977

SUPPRESSED GRAND FIR AND SHASTA RED FIR RESPOND WELL TO RELEASE

by

K. W. Seidel, *Silviculturist*

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ABSTRACT

The 5-year growth response of a 43-year-old, suppressed, even-aged grand fir-Shasta red fir stand of advance reproduction was measured in central Oregon after release and thinning. Both diameter and height growth of the seedlings and saplings responded immediately after competition of the lodgepole pine overstory was eliminated--the growth rate increasing two to three times above the 5-year pre-release rate. Spacing treatments had no differential effect on growth response of the fir understory; both species responded similarly except for a greater number of epicormic branches on grand fir.

KEYWORDS: Release, competition (plant), advance growth, growth response, grand fir, *Abies grandis*, Shasta red fir, *Abies magnifica*.

INTRODUCTION

The upper slope mixed conifer forests of eastern Oregon and Washington are some of their most productive forests. Additional information, however, is needed on the growth and yield of managed stands. True firs are an important component of these mixed conifer forests, but no information is available regarding the growth of true fir stands under various spacing and thinning regimes.

In 1970, a study was begun in a suppressed even-aged stand of grand fir (*Abies grandis* (Dougl.) Lindl.) and Shasta red fir (*A. magnifica* var. *shastensis* Lemm.) in central Oregon. The purpose of this study was to obtain data on growth of grand and Shasta red fir at several spacings and under a progressive thinning schedule. This paper reports results from the first 5-year period of the study.

STUDY AREA AND METHODS

The study site is located on the Lookout Mt. unit of the Pringle Falls Experimental Forest about 35 miles (56 km) southwest of Bend, Oregon on a north-facing 13-percent slope at an elevation of about 5,600 feet (1 706 m). The soil is a well-drained Regosol (Longbell series) developed in dacite pumice orginating from the eruption of Mount Mazama (Crater Lake) 6,500 years ago. It has an A1, AC, C1, C2 pumice horizon about 3 feet (0.9 m) deep over the buried soil.

Before study installation, the timber stand consisted of 75-year-old lodgepole pine (*Pinus contorta* Dougl.) overstory with a 43-year-old grand fir-Shasta red fir seedling and sapling understory averaging about 4.5 feet (1.4 m) in height. About 70 percent of the understory was less than 0.6-inch (1.5-cm) d.b.h., and average d.b.h. of measurable trees was about 1 inch (2.5 cm). Site index of older red fir in the area based on Schumacher's (1928) curves indicates a height of 65 feet (20 m) at age 50. Site index based on curves of DeMars et al. (1970) shows a height of 120 feet (37 m) at age 100. The lodgepole basal area averaged about 150 ft^2 per acre (34.4 m^2/ha) and there were about 3,000 fir trees per acre (7 410/ha) in the understory.

The study area is located in an *Abies magnifica shastensis/Chimaphila umbellata* plant community (Franklin and Dyrness 1973, p. 155). Ground vegetation is sparse, consisting primarily of prince's pine (*Chimaphila umbellata*). Small amounts of other genera such as *Arctostaphylos*, *Stipa*, *Carex*, and *Epilobium* are also present.

The study in the fir understory consists of two closely related parts. The first part is an initial spacing experiment testing four spacings (6-, 12-, 18-, and 24-foot; 1.8-, 3.7-, 5.5-, and 7.3-m) created by thinning in 1970. Each spacing was replicated two times making a total of eight plots. Twenty-four trees were measured in each plot; thus plot size including buffer strips ranged from 0.14 acre (0.06 ha) to 0.64 acre (0.26 ha), depending upon the spacing. No further thinning will be done in these plots.

The second part of the study is a progressive thinning experiment with a design similar to O'Conner's (1935) consisting of eight 0.25-acre (0.10-ha) plots. All plots were thinned to a 6-foot (1.8 m)-spacing in 1970. When

diameter growth on these plots decreases 0.1 inch (0.25 cm) or more from the previous year, six of the eight plots will be thinned to a 12-foot (3.7-m) spacing. When growth on these six plots again slows, four of the six will be thinned to a 18-foot (5.5-m) spacing. This progressive thinning will continue until there are two plots at each of four final spacings equal to those in the initial spacing experiment. This will permit a comparison of volume growth and yield between the initial spacing plots (part 1) and the plots thinned over a number of years to the same final spacings (part 2).

After plots were established in the study area, the lodgepole pine overstory was killed with 2,4-D [(2,4-dichlorophenoxy) acetic acid] to release the fir understory without logging damage and provide a partial shade for a few years after release. Some fir seedlings near the plots were transplanted onto the plots to improve the spacing.

Total height of all plot trees was measured to the nearest 0.1 foot (0.03 m) and d.b.h. of trees 0.6 inch (1.5 cm) or larger was measured to the nearest 0.1 inch (0.25 cm) in 1971 and 1975. Diameter breast height was measured annually on a 10-percent random sample of trees on the fixed area plots. In 1976, 50 trees of each species were randomly chosen from trees in the buffer strips and cut at the ground line for measurements of diameter growth during the 5-year period before and after release. Also in 1976, the 5-year pre-release height growth of all trees in the initial spacing plots and the 10-percent sample in the fixed area plots were measured by counting whorls. Crown diameter and height to live crown were measured on 10 trees per plot on the initial spacing (variable area) plots in 1971 and 1975.

After thinning, average height of trees on the eight fixed area plots was 4.6 feet (1.4 m) and ranged from 3.8 to 5.6 feet (1.2 to 1.7 m) on the variable area plots (table 1). Average d.b.h. of trees of measurable size was about 1 inch (2.5 cm). Of the trees in the fixed area plots, 59 percent were grand fir compared with 81 percent in the variable area plots.

Table 1--*Characteristics of grand fir-Shasta red fir plots after initial 1970 thinning and 5 years later (per acre)*

Spacing	Species composition		Number of trees	Trees less than 0.6-inch d.b.h.		Quadratic mean diameter[1]	Average height	Average crown diameter		Average height to live crown		Average live crown ratio	
	Grand fir	Red fir						Grand fir	Red fir	Grand fir	Red fir	Grand fir	Red fir
Feet	- - Percent - -			Number	Percent	Inches	Feet	- - Feet - -		- - Feet - -		- - Percent - -	
After thinning (1970):													
Fixed area plots													
6 by 6	59	41	1,169	817	70	1.0	4.6	-- [2]	--	-- [2]	--	-- [2]	--
Variable area plots													
6 by 6	81	19	1,200	975	81	1.2	3.8	3.2	2.7	2.3	2.1	58.6	52.7
12 by 12	79	21	304	158	52	1.1	5.6	3.5	3.8	2.6	2.9	61.9	64.5
18 by 18	92	8	134	103	77	0.9	4.3	3.1	3.5	2.4	2.4	57.3	66.4
24 by 24	71	29	76	63	83	1.0	4.1	3.3	3.4	2.1	2.3	62.0	57.1
1975:													
Fixed area plots													
6 by 6	59	41	1,114	498	45	1.5	6.7	-- [2]	--	-- [2]	--	-- [2]	--
Variable area plots													
6 by 6	81	19	1,200	800	67	1.2	5.3	4.6	3.9	0.9	2.1	87.0	61.1
12 by 12	79	21	304	95	31	1.8	8.0	5.2	6.6	1.5	2.0	83.3	83.8
18 by 18	92	8	132	61	46	1.4	6.5	4.6	5.1	1.3	2.1	84.2	80.6
24 by 24	71	29	76	33	43	1.3	6.0	4.9	4.8	1.3	2.2	83.8	70.6

[1] All trees 0.6-inch d.b.h. and larger.

[2] Crown dimensions not measured on fixed area plots.

Diameter and height growth differences between species were analyzed with a t-test. Growth differences among the initial spacing plots were analyzed using analysis of variance in a completely randomized design. Height growth was also subjected to an analysis using initial height before release and thinning as the covariate. No analyses were applied to data from the fixed area plots since they are now all at the same spacing. The word significant is used in the statistical sense.

RESULTS

Diameter Growth

Diameter growth was not affected by variations in spacing. During the 5 years after release, annual growth averaged 0.16 inch (0.41 cm) on the 12-, 18-, and 24-foot (3.7-, 5.5-, and 7.3-m) spacings and 0.15 inch (0.38 cm) on the 6-foot (1.8-m) spacing (table 2). On the eight fixed area plots now at a 6-foot (1.8-m) spacing, periodic annual diameter growth averaged 0.15 inch (0.38 cm) and the difference in growth between grand fir (0.14 inch; 0.36 cm per year) and red fir (0.16 inch; 0.41 cm per year) was not significant.

Table 2--*Periodic annual diameter growth and changes in crown dimensions of grand fir-Shasta red fir saplings after release and initial thinning at age 43*

Spacing	Diameter growth[1]	Changes in:					
		Crown diameter		Height to live crown		Live crown ratio	
		Grand fir	Red fir	Grand fir	Red fir	Grand fir	Red fir
Feet	Inches	- - - Feet - - -		- - - Feet - - -		- - Percent - -	
Fixed area plots:							
6 by 6	0.15	--	[2] --	--	[2] --	--	[2] --
Variable area plots:							
6 by 6	0.15	+1.4	+1.2	-1.4	0	+28.4	+8.4
12 by 12	0.16	+1.7	+2.8	-1.1	-.9	+21.4	+19.3
18 by 18	0.16	+1.5	+1.6	-1.1	-.3	+26.9	+14.2
24 by 24	0.16	+1.6	+1.4	-0.8	-.1	+21.8	+13.5
Mean	0.16	+1.6	+1.8	-1.1	-.3	+24.6	+13.9

[1] Arithmetic mean diameter growth of trees 0.6-inch d.b.h. or larger in 1970 and living through the 5-year period. Diameter growth may not agree with difference between mean diameters at beginning and end of growth period in table 1 because average plot diameters at each measurement are based on trees 0.6-inch d.b.h. or larger at that time but growth is based only on trees of measurable size in 1971.

[2] Crown dimensions not measured on fixed area plots.

The pronounced effect of release on the fir understory is evident by a comparison of diameter growth rates of the cut trees before and after release. For both species, the average growth during the 5-year period before release was about 0.04 inch (0.10 cm) per year; this increased nearly threefold to 0.11 inch (0.28 cm) per year in the 5 years after release. Not only was the average annual diameter growth greater after release, but the response occurred the 1st year; averaging 0.13 inch (0.33 cm) on the 10-percent sample measured annually in the fixed area plots.

Height Growth

Height growth between species did not differ significantly over the 5-year period on either fixed or variable area plots, ranging from 1.6 to 2.4 feet (0.49 to 0.73 m) for grand fir and from 1.2 to 2.6 feet (0.37 to 0.79 m) for red fir (fig. 1). No significant difference in height growth existed between the initial spacing plots for both species combined.

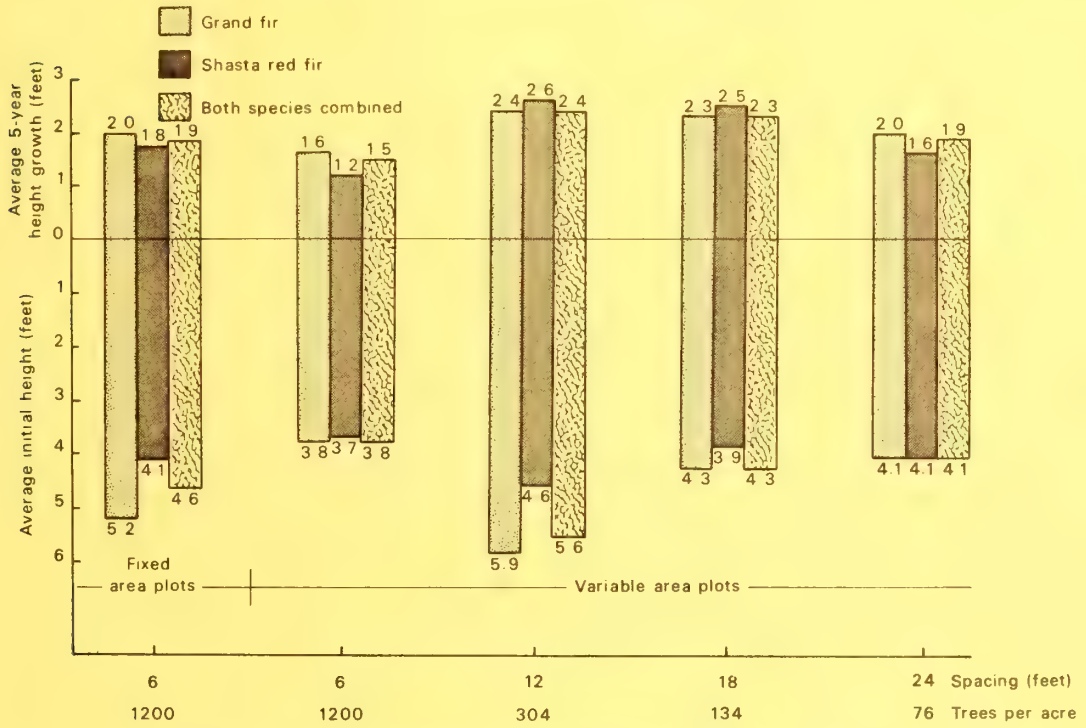

Figure 1.--Initial height in 1970 and 5-year height growth after release by species and spacing level. Based on growth of all trees living through the 5-year period.

Similar to diameter growth, the trees responded to release by faster height growth. Trees were growing about 0.2 foot (0.06 m) in height per year during the 5 years before release. In the same length of time after release, the average growth rate doubled to about 0.4 foot (0.12 m) annually. Heights were not measured annually, but it was obvious from observations that height growth response occurred the first growing season after release.

Height growth of individual trees after release varied widely, ranging from 0 to 7.0 feet (2.1 m) during the 5 year period. A linear regression of height growth on live crown ratio, even though significant, was of no value in predicting height growth since only 16 percent of the variation in height growth was explained by live crown ratio.

Mortality

Nearly all of the mortality that occurred on the plots was transplanted seedlings. Of the 2,530 trees in the study, 111 died; all but 8 of these

were transplanted trees. No snow damage was observed after release and thinning except for a few trees with small crowns that were growing in dense clumps before thinning.

Crown Dimensions

During the 5-year period after release, average crown diameter of grand fir increased by 1.6 feet (0.49 m) compared to an increase of 1.8 feet (0.55 m) for red fir (table 2). Spacing had no significant effect on crown diameter growth.

Because of more epicormic branching on grand fir than on red fir after release and thinning, height to live crown decreased by an average of 1.1 feet (0.34 m) for grand fir, but only by 0.3 feet (0.09 m) for red fir, a significant difference (table 2).

DISCUSSION

Meaningful volume growth and yield data in relation to spacing and thinning regimes will be available in the future from this study. At this time, the results indicate the growth potential of managed true fir stands on good sites such as this. Because of their shade-tolerance, many true fir seedlings and saplings retain relatively full crowns even though suppressed for many years in an understory position and thus can respond rapidly to increased growing space from release and thinning.

I am not suggesting that the growth response found in this study after releasing the understory by killing the overstory will correspond exactly to the response of advance reproduction after release by overstory removal but it is very similar to that reported by Gordon (1973) in northern California for understory true fir of about the same age and size. He found a marked increase in diameter growth within 1 to 2 years after release by logging the overstory and a fourfold increase in height growth, but increased height growth rate was not observed until the 5th year after release. He also reported that trees taller than 6 feet died only if they had been damaged and that a higher relative mortality rate occurred in firs less than 1 foot tall. I have also measured a growth response comparable to that found in this study on understory fir saplings released after overstory removal in another study in eastern Oregon.[1/]

With adequate growing space, the growth rate of suppressed understory trees is a function of vigor at time of release. Most of the trees in this study are vigorous, full crowned trees with live crown ratios greater than 40 percent, thus showing a large and rapid response to release. On the other hand, a few trees with very small crowns (less than 20-percent live crown) showed little or no growth. The weak relationship between live crown ratio and height growth may be improved by the inclusion of additional variables such as diameter, height, and crown surface area in the regression. Studies are underway to more accurately define tree parameters related to growth response of suppressed true fir advance reproduction.

[1/] Unpublished data on file at Silviculture Laboratory, Bend, Oreg.

Preservation of vigorous, undamaged true fir understories by careful logging of the overstory is a sound silvicultural practice. This avoids the loss of growth associated with eliminating the advance reproduction and the uncertainties of obtaining new seedling reproduction. Barrett et al. (1976) have shown that it is possible to preserve adequate numbers of understory ponderosa pine (*Pinus ponderosa*) saplings by marking the potential crop trees before logging and by unconventional slash disposal methods. Similar techniques should be applicable to mixed conifer stands of eastern Oregon where topography permits tractor logging.

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* * * * *

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COMPUTER PLOTTING OF GRAPHS FOR REPORTS

by

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and

Delbert E. Thompson, *Illustrator*

ABSTRACT

Computer plotting can aid forest scientists and forest land managers by increasing the speed and accuracy of graph preparation. This report outlines computer data requirements for common graph types and also gives computer data requirements for special plotting techniques.

Graphs that are included are (1) the equation graph, (2) the scatter diagram, (3) the combination equation graph and scatter diagram, (4) the line graph, and (5) the histogram. Although this paper is not a user's manual for a particular machine, it should be noted that a general plotting program is available for the Wang 700B - 720C programable calculators.

KEYWORDS: Computer plotting, graphs, histograms.

INTRODUCTION

The primary purpose of this paper is to anticipate that in the future most manuscript graphs likely will be drawn by machine; therefore, plotting data will have to be submitted in a standard format. Another purpose is to inform scientists and land managers of the capabilities and advantages of computer plotting and that a general plotting program exists for the Wang 700A - 720C programable calculator series.[1]

[1]The use of trade names and equipment in this paper shall not be construed in any way to be a recommendation or endorsement by U.S. Department of Agriculture, Forest Service.

This paper is not a user's manual for the Wang 700A - 720C programable calculator series. The plotting data requirements are general setup instructions that should be followed no matter what computer system is used. These instructions will help scientists and land managers communicate with the programer and will guide the programer when he is programing the problem for the computer.

A wide range of plots such as three dimensional surfaces, maps, powerline towers, logging systems, tree stem profiles, histograms, and various types of graphs have been drawn with the computer. This list is incomplete, but it exemplifies the capabilities of computer plotting.

Speed and accuracy are the main advantages of computer plotting. Machine-plotted graphs are produced in 10-15 minutes, and accuracy is limited only by the input data and the resolution of the plotting device. (The resolution of the plotting device is usually inconsequential.) If a graph is similar to the common types presented in this report and the data are submitted as requested, the scientist or land manager need not spend much time producing highly accurate graphs for manuscripts.

A short discussion of the organization of this paper is necessary before examples of the most common types of graphs and their specific data requirements are presented. The report has three parts: (1) general plotting information required for all graphs, (2) common graph types and their individual data requirements, and (3) special plotting techniques.

Normally, only the data requirements given in parts 1 and 2 are considered for a common graph type. Part 3 deals with special plotting techniques that scientists or land managers occasionally might use when presenting data or results in graphic form. Any combination of the special plotting techniques can be used on a single graph.

Occasionally, two or more of the common graph types from part 2 are combined to form a single graph. When this occurs, the specific data requirements for each graph type in the combination must be met before the combination graph can be drawn.

GENERAL PLOTTING INFORMATION REQUIRED FOR ALL GRAPHS

There are four distinctive line types: (1) solid line, (2) dash line, (3) dotted line, and (4) the dash-dot line. These line types are the ones most used when plotting; however, additional line types can be created by varying the length of the dashes in the dash and dash-dot lines. It is recommended that no more than six line types be used on any one graph.

For computer plotting, five symbols are used. They are:

(1) dot . ,

(2) plus + ,

(3) square □ ,

(4) hexagon ⬡ (this looks like a circle when plotted), and

(5) triangle △.

For scattered diagrams and other graphs that require the plotting of individual data points, it is recommended that the data be on standard 80-column computer cards. The x and y variables must appear on the computer card in the same format for any given batch of data; however, the format can be varied from one batch to another. For each batch, the card columns that the x and y variables occupy must be indicated along with the proper placement of decimal points. If the data are not on cards, a list of the x and y coordinates will be adequate.

The plotting data needed irrespective of graph type are:

(1) type of graph to be plotted,
(2) publication figure number,
(3) figure label,
(4) length of the x-axis in inches (maximum length allowed is 12 inches),
(5) length of the y-axis in inches (maximum length allowed is 8 inches),
(6) minimum value on the x-axis scale (if an axis has nonsequential numbering, letters, or special labels, submit an example of the axis. Designate the axis as shown on the General Plotting Information Form in the appendix.),
(7) maximum value on the x-axis scale,
(8) scale interval for the x-axis scale,[2]
(9) minimum value on the y-axis scale,
(10) maximum value on the y-axis scale,
(11) scale interval for the y-axis scale (see footnote 2), and
(12) axis labels.

The General Plotting Information Form in the appendix was created to facilitate the recording of general plotting data. This form outlines the general plotting information required of all graphs.

[2]Scale intervals may be adjusted by the illustrator.

COMMON GRAPH TYPES AND THEIR INDIVIDUAL DATA REQUIREMENTS

Equation Graph

Frequently, in the course of a research study, an equation is developed that relates one dependent variable with one or more independent variables. When such an equation is published, a graph of the equation is often included to help the reader understand the results.

The number of independent variables present in an equation determines whether the graph will be a single curve or a family of curves such as shown in figure 1. The single curve is produced by varying only the x-axis variable when solving for the corresponding y-axis values. A family of curves is produced when the x-axis variable is varied for different levels of a second independent variable. In figure 1, the height equation (Curtis et al. 1974) was solved for various ages while site index was held at given levels.

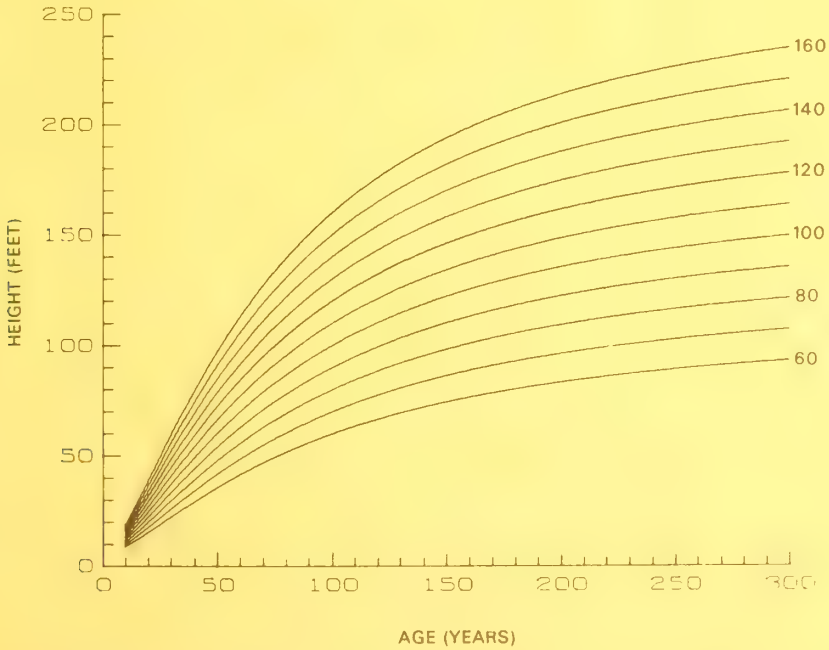


Figure 1.--Equation graph. Height growth curves for Douglas-fir.

Together with the general plotting information, specific data needed for an equation graph are:

(1) The equation should be in a form such that the y-axis value is easily calculated when numerical values are substituted for the independent variables. The form is: y-axis value = (some algebraic expression).

(2) The x-axis variable must be identified, and the minimum and maximum values to be substituted in the equation must be given.

(3) If a second independent variable is also used, identify the variable and list the values to be substituted for it in the equation.

(4) Designate the type of line desired.

(5) Provide labels if curves need to be identified.

If more than one equation is to be plotted on a graph, the preceding information must be given for each equation on the graph. It should be noted that the scientist need not solve an equation for plotting points.

Scatter Diagram

The specific data needed for a scatter diagram are:

(1) The x-y coordinate values for a each data point--if this information is available on computer cards, submit a data deck;

(2) The type of symbol to be used when plotting a group of data points--this especially is important when several groups of data are plotted on one graph; and

(3) Any labels to be used for identifying the groups of data.

Figure 2 is an example of a scatter diagram that has three data groups represented.

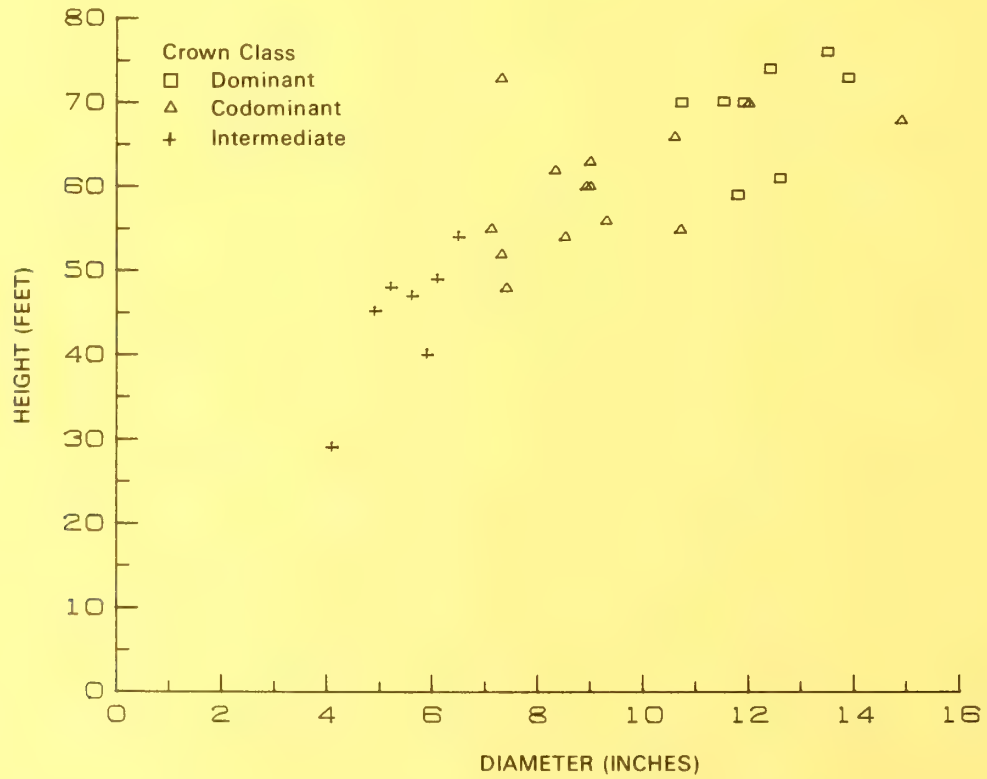


Figure 2.--Scatter diagram. Height-diameter relationship for a ponderosa pine stand by crown classes.

Combination Equation Graph and Scatter Diagram

Data needed for this graph are the combination of the data required for an equation graph and the data required for a scatter diagram. Usually, this type of graph is used for comparing a regression equation to the data from which it was derived, as is shown in figure 3 (Rothacher 1973). Plotting data for figure 3 are given in the appendix as an example of how plotting data should be set up for computer plotting.

Histograms

There are many types of histograms as illustrated by figures 4, 5, and 6; however, they all have the same data requirements. Items needed to draw histograms are:

(1) The number of bars to be centered around an x-axis scale value (see examples),

(2) A sketch of the x-axis (General Plotting Information Form),

(3) The y-axis scale value of each histogram bar along with the bar's position on the x-axis, and

(4) Bar labels, if needed.

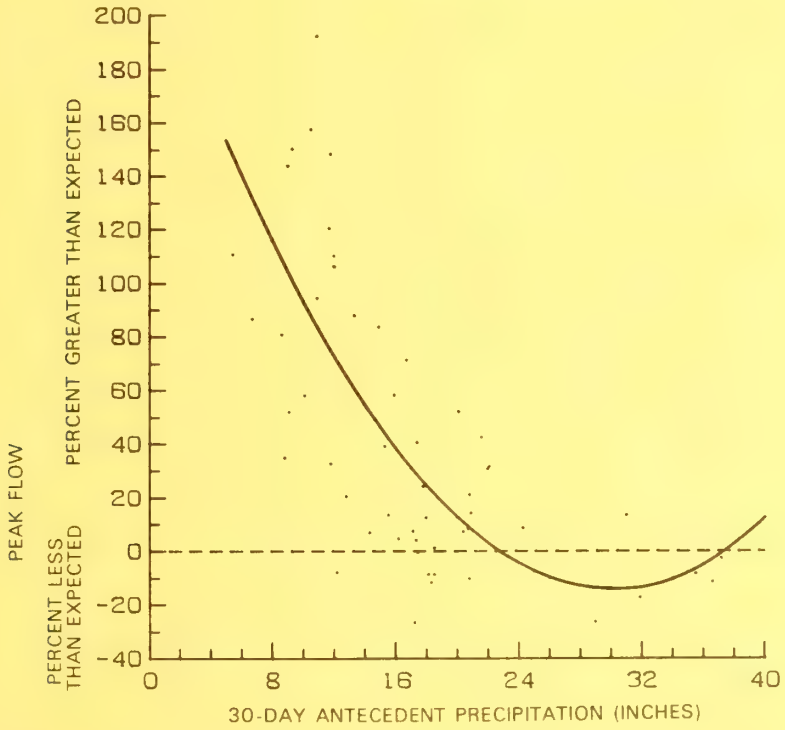


Figure 3.--Combination equation graph and scatter diagram. Figure title from Rothacher (1973) was: "Measured peak streamflow as a percent of predicted peak at various degrees of wetness as expressed by 30-day antecedent precipitation."

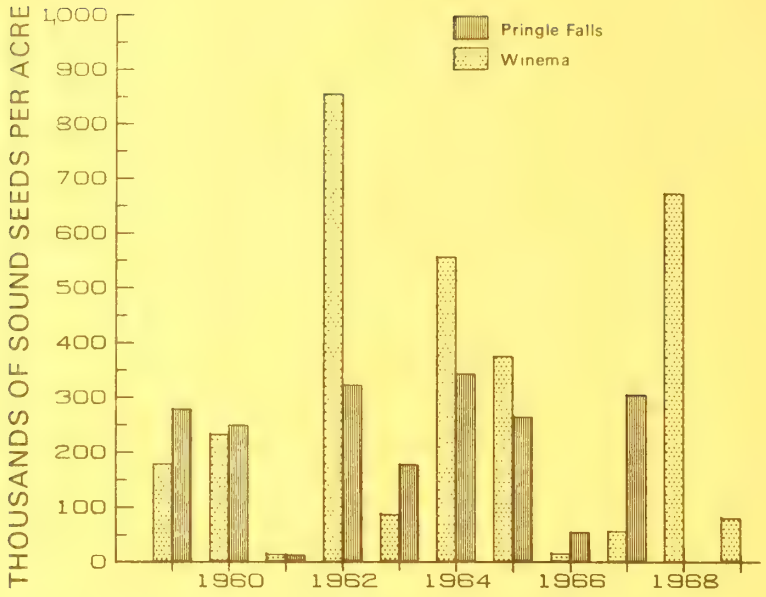


Figure 4.--Histogram--Two bars centered on each x-axis scale value (from Dahms and Barrett 1975, reproduced with permission). Figure title as it appeared in Dahms and Barrett, "Number of sound lodgepole pine seeds per acre on the Winema and Pringle Falls areas."

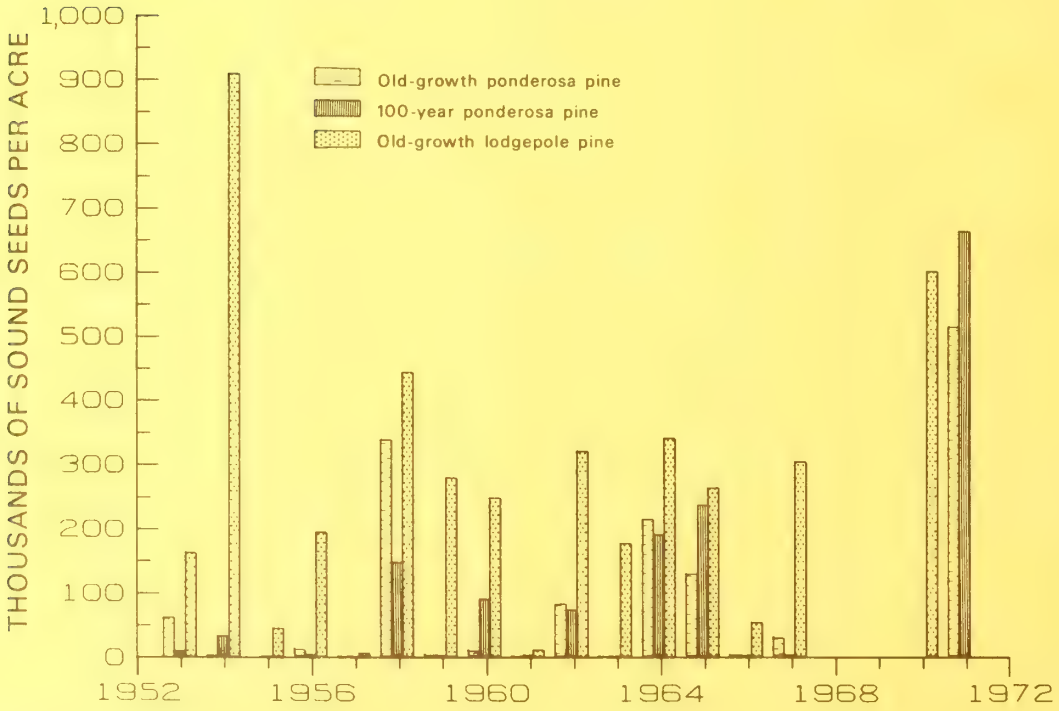


Figure 5.--Histogram--Three bars centered on each x-axis scale value (from Dahms and Barrett 1975, reproduced with permission). Figure title as it appeared in Dahms and Barrett: "Sound seeds per acre by year for old-growth ponderosa pine, 100-year ponderosa pine, and old-growth lodgepole pine. Pringle Falls study (data missing for 1968, 1969, 1970, and 1971 were destroyed by the 1974 fire at the Silviculture Laboratory in Bend)."

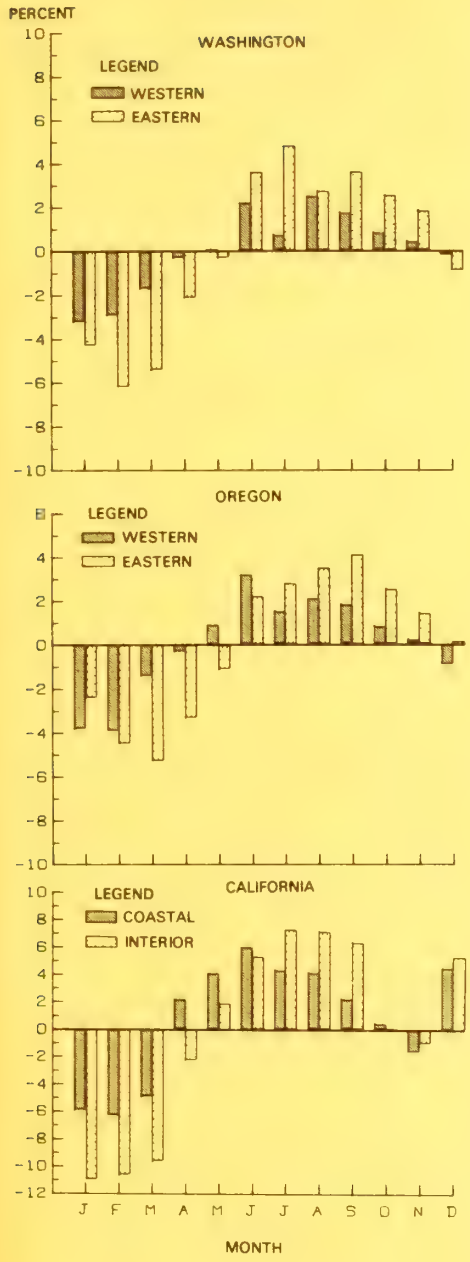


Figure 6.--Histograms--Two bars centered on each x-axis scale value. The zero value of the y-axis is not located at the origin of the graph. Also, this graph is an example of graph stacking. (From Wall and Oswald 1975, reproduced with permission.) Figure title as it appeared in Wall and Oswald, "Monthly deviations from average employment in sawmills and planing mills in Washington, Oregon, and California, 1969-71."

Line Graphs

Figure 7 (Hickman 1975) is an example of a line graph that shows trends for various data groups. Each line on the graph is made up of individual data points connected by straight lines. Data to be supplied for each line on the graph are:

(1) The x-y coordinates for the individual data points that make up the line. If this information is on computer cards, submit a data deck;

(2) The type of line to use between data points;

(3) Symbol to be used for the data points; and

(4) Labels to be used for line identification.

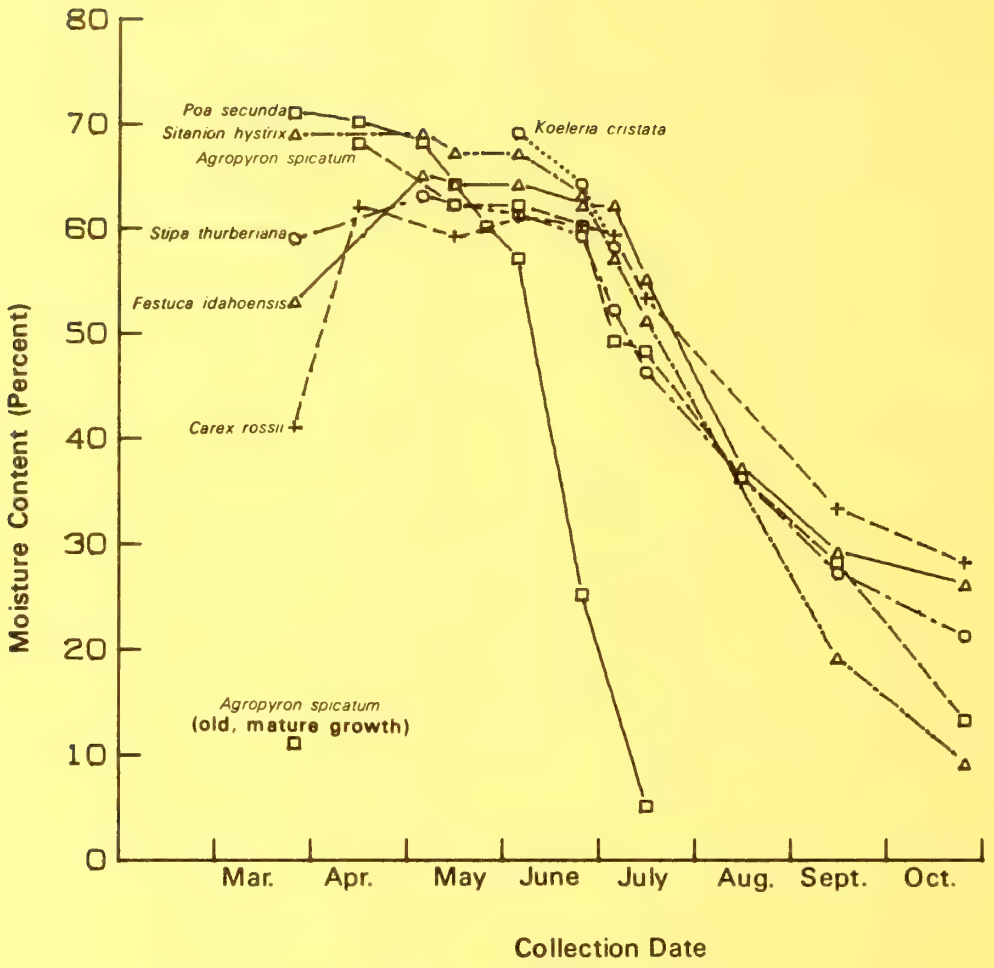


Figure 7.--Line graph (from Hickman 1975, reproduced with permission). Figure title as it appeared in publication, "Seasonal moisture trends in herbaceous species."

SPECIAL PLOTTING TECHNIQUES

Special plotting techniques are used to save space and to present graphs more effectively. The graphs presented in this section are the results of computer plotting, hand touchup, cutting, pasting, and photocopying. These graphs illustrate that, with a minimum of handwork, computer plots can be altered or combined to present results in various ways.

Second y-axis Scale

Sometimes a second y-axis scale is needed on a graph to facilitate a special set of data as shown in figure 8 (Hickman 1975) or to show results in metric units. Data needed for such cases are:

(1) Length of second y-axis in inches,
(2) Minimum scale value to appear on the second y-axis,
(3) Maximum scale value to appear on the second y-axis,
(4) Scale interval desired on the second y-axis,
(5) Axis label,
(6) Any data to be plotted using the second y-axis scale, and
(7) Data labels.

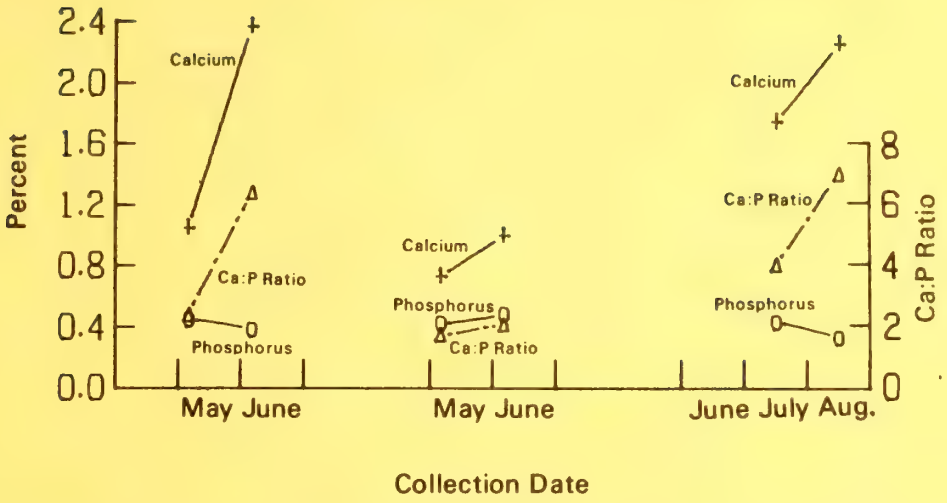


Figure 8.--Second y-axis scale (from Hickman 1975, reproduced with permission). Figure title as it appeared in publication, "Seasonal trends of constituents in tall western senecio, mountain lily, and Oregon sidalcea."

Break Lines in Axes

If a graph (fig. 9, Wall and Oswald 1975) has break lines in any of its axes, a sketch of the axis should be given along with the other plotting data. The sketch can be drawn on the General Plotting Information Form and must include:

(1) The location of all break lines and

(2) The scale values desired on each side of a break line.

Stacked Graphs

Stacked graphs, as shown in figures 10 and 11, are possible only if the x-axis is the same for all the graphs to be stacked. The data needed for graph stacking are:

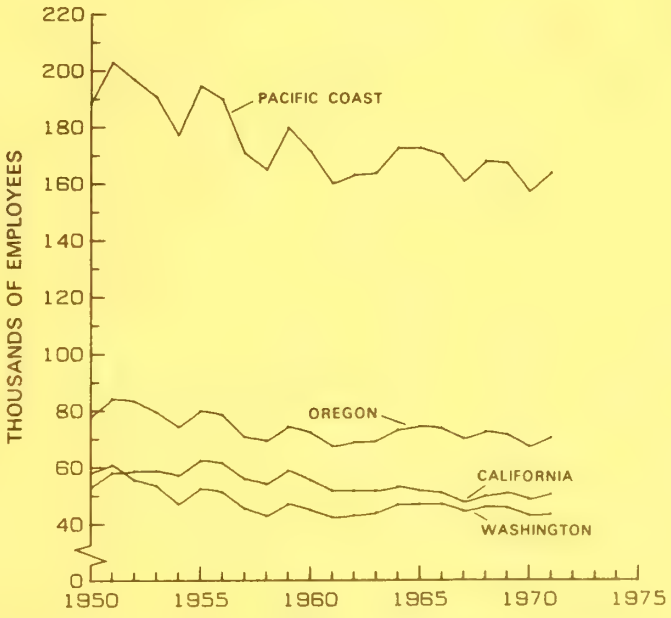
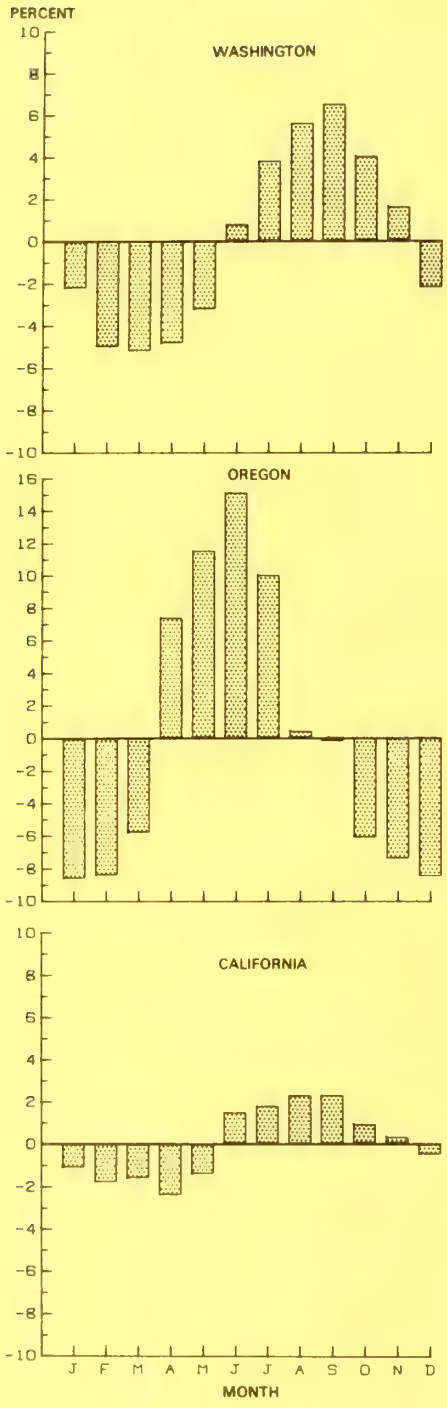


Figure 9.--Break line in axis (from Wall and Oswald 1975, reproduced with permission). Figure title as it appeared in publication, "Average annual employment in the lumber and wood products industry on the Pacific coast by State, 1950-71."



(1) A sketch of the stack (use General Plotting Information Form),

(2) The number of graphs to be stacked (recommended limit = 4),

(3) The order of stacking, and

(4) The plotting data for each graph in the stack.

Logarithmic Plotting

Converting data to logarithms (base 10) and plotting the transformed data on logarithmic scales can be done on the computer. Common graph types that are sometimes plotted in logarithms are the equation graph, scatter diagram (fig. 12), and combination equation graph-scatter diagram. Designation of the x- or y-axis, or both, is necessary for logarithmic plotting.

Figure 10.--Stacked histograms (from Wall and Oswald 1975, with permission). Figure title as it appeared in publication, "Monthly deviations from average employment in the paperboard container and box industry in Washington, Oregon, and California, 1969-71."

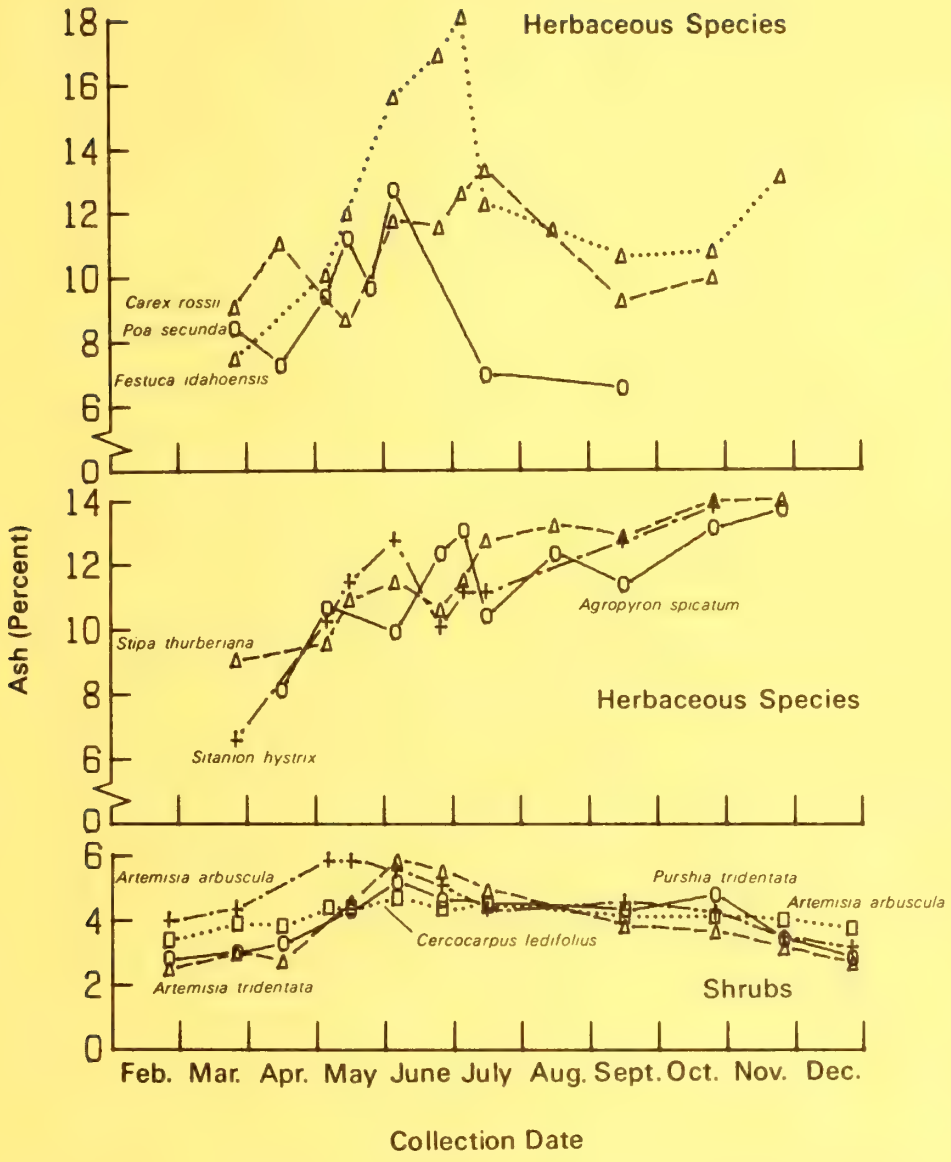


Figure 11.--Stacked line graphs (from Hickman 1975, reproduced with permission). Figure title as it appeared in publication, "Seasonal trends of ash (total mineral matter)."

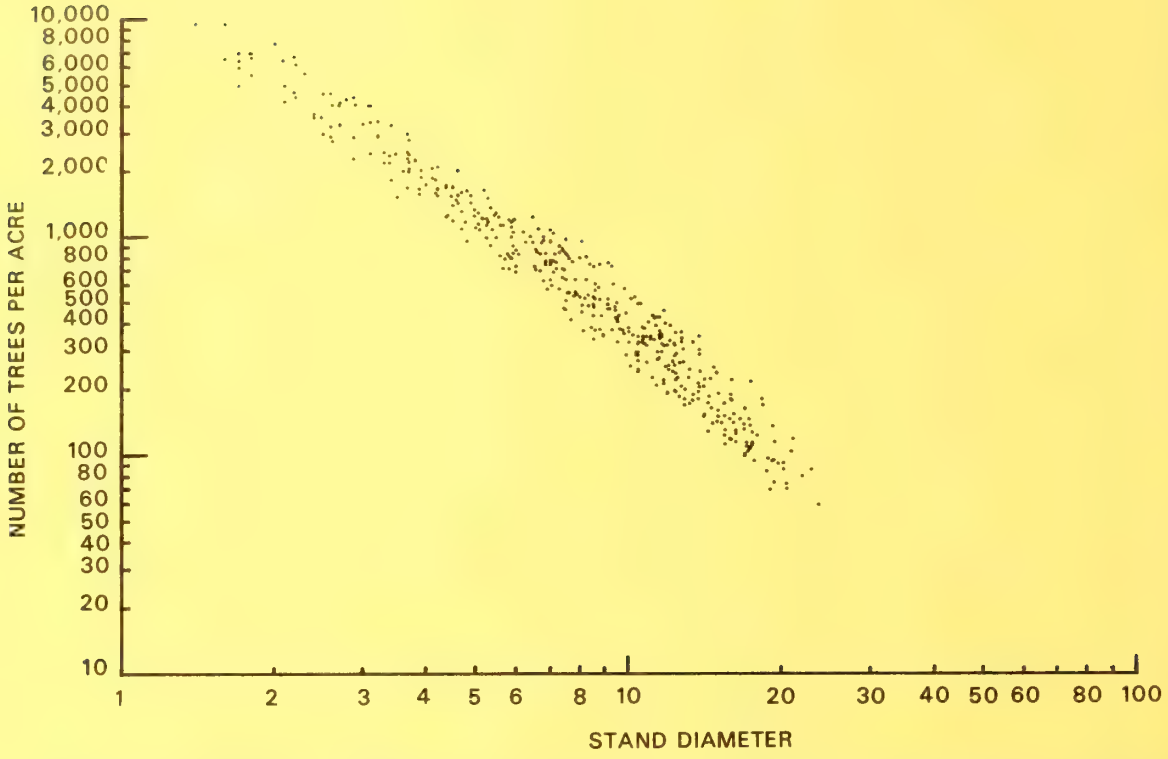


Figure 12.--Number of ponderosa pine trees per acre over average stand diameter plotted on logarithmic scales.

SUMMARY

Drawing graphs by computer can aid forest research scientists and forest land managers in data analysis and in report preparation. Many graphs of high quality can be drawn in a few minutes at a fraction of the cost of hand-drawn graphs.

To take advantage of computer plotting, the scientist or land manager must be able to communicate with the programer doing the plotting. This paper outlines information a programer would need to plot certain types of graphs and gives a format for organizing plotting information.

The types of graphs presented are (1) the equation graph, (2) the scatter diagram, (3) the combination equation-graph and scatter diagram, (4) the line graph, and (5) the histogram. Data requirements for each graph are given, and at least one example of each graph is presented. In addition, special plotting techniques such as stacking graphs, breaking lines on the axis, a second scale for the y-axis, and logarithmic plotting are explained and shown.

It should be noted that a general plotting program was written for the Wang 700A - 720C programable calculator series. The plotting data requirements are general setup instructions that should be followed no matter what computer system is used for the plotting.

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APPENDIX

General Plotting Information Form

Name of publication *Computer Plotting of Graphs for Reports*

Author(s) *Donald J. DeMars and Delbert E. Thompson*

Figure No. *3*

Figure label *Combination Equation Graph and Scatter Diagram*

Type of graph: Equation ☐ Scatter diagram ☐

Combination equation and scatter diagram [X]

Histogram ☐ Line graph ☐ Part of a combination ☐

Length of axis: x axis *5.5 inches* y axis *6.0 inches*

Axis scale values: x-axis min. *0* x-axis max. *40*

x-axis scale interval *8*

y-axis min. *-40* y-axis max. *200*

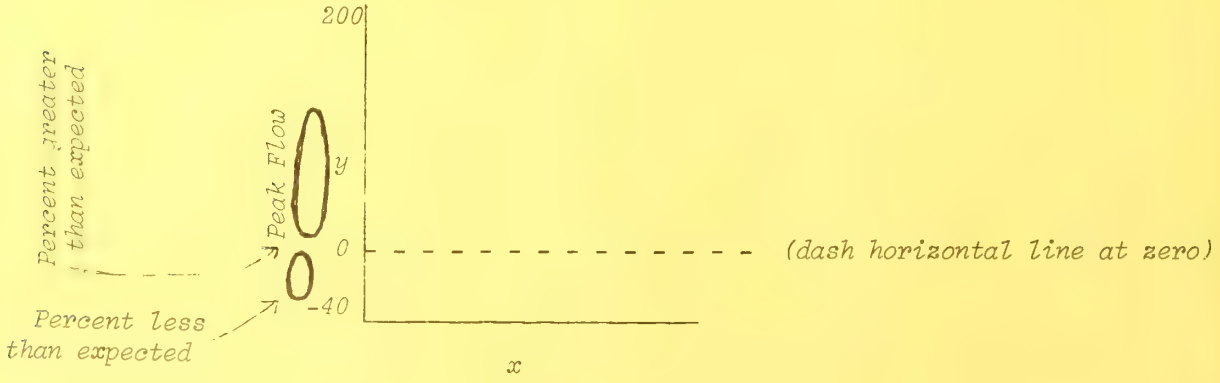
y-axis scale interval *20*

Axis labels: x-axis *30-day antecedent precipitation (inches)*

y-axis *Peak Flow*

Percent less than expected *Percent greater than expected*

Axis and/or data sketch if needed:



Example of xy coordinates for figure 3:

x	y	x	y
9.3	150.4	18.0	-9.0
17.8	23.7	18.5	-8.5
18.0	12.0	8.7	35.2
20.8	-10.9	10.9	95.0
24.3	9.0	17.3	3.8
21.9	31.1	16.6	71.8
31.9	-17.8	10.8	192.8
37.2	-2.3	11.8	148.3
35.4	-9.0	8.9	143.7
36.6	-12.1	12.8	20.3
30.9	13.8	8.5	81.2
28.9	-26.8	11.8	32.5
22.0	31.8	11.6	121.2
15.2	39.5	12.2	-8.1
6.6	86.7	10.0	58.6
14.9	83.1	14.3	6.8
16.2	4.1	17.4	41.0
20.8	21.3	17.1	-27.0
9.0	52.2	17.0	8.0
5.3	110.8	15.4	14.0
10.5	157.7	18.5	1.0
12.0	105.7	18.2	-12.0
13.3	88.5	20.9	14.0
15.9	58.2	21.6	43.0
20.7	8.1	20.3	7.0
20.0	52.7	17.9	-1.0

Type of symbol: dot

Example of equation for figure 3:

$y = 227.52176 - 16.147861(x)+0.2693494(x^2)$

where: y = Peak flow in percent

x = 30-day antecedent precipitation

Minimum value of x = 4

Maximum value of x = 40

Type of line--solid

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USDA FOREST SERVICE RESEARCH NOTE

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PNW-290 February 1977

RELEASES OF RECENTLY IMPORTED LARCH CASEBEARER PARASITES FOR BIOLOGICAL CONTROL IN THE WESTERN UNITED STATES, INCLUDING RELOCATIONS OF *AGATHIS PUMILA*

by

R. B. Ryan, W. E. Bousfield, C. W. Johanningmeier,

G. B. Parsons, R. F. Schmitz, and L. J. Theroux[1/]

ABSTRACT

Releases of *Chrysocharis laricinellae*, *Dicladocerus westwoodii*, *Dicladocerus japonicus*, *Elachertus argissa*, *Necremnus metalarus*, (all, Hymenoptera: Eulophidae), and *Agathis pumila* (Hymenoptera: Braconidae), for biological control of the larch casebearer in Washington, Oregon, Idaho, and Montana included some newly imported stocks and additional release locations.

Keywords: Parasites (insect) (-forest pest control, larch casebearer, biological control (-forest pests.

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INTRODUCTION

The larch casebearer, *Coleophora laricella* (Hbn.), is an introduced pest of western larch, *Larix occidentalis* Nutt. Since its discovery near St. Maries, Idaho, in 1957 (Denton 1958), this insect has caused repeated defoliation in some areas of northern Idaho, resulting in serious branch dieback and reductions in radial increment of up to 90 percent (Tunnock et al. 1969). The larch casebearer is now found over much of the distribution of western larch in Idaho, Montana, northeastern Washington, and southern British Columbia. The infestation is still spreading and intensifying in the Blue Mountains of Oregon and in the Cascade Range of Washington.

A biological control program of parasite introductions was initiated in 1960 in an effort to combat this pest. About 2,400 adults of the European parasite, *Agathis pumila* (Ratz.), were reared from an earlier establishment site in Rhode Island and shipped to Idaho where they were released on five sites (Denton 1972). The parasite was obviously adapted to at least some localities in the West, because it was recovered on the release plots in 1962 and 1963. Region 1 entomologists imported and released a new supply of *A. pumila* to aid in its spread throughout the growing range of the casebearer. In 1964 and 1965, infested larch branches from Vermont and Massachusetts were set up for rearing *A. pumila* in a large outdoor cage in Sandpoint, Idaho, where emerging *A. pumila* were collected and transferred into other cages containing locally derived host stock (Denton, personal communication). Branches from these latter cages, bearing overwintering, parasitized larvae, were transferred to about 375 sites throughout the infested zone. Bousfield et al. (1974) reported sampling 173 of the *A. pumila* release sites and finding *A. pumila* established at about half the sites.

Effectiveness of *A. pumila* has varied widely at the locations where it has become established. Our best long-term evaluation of its performance under western conditions is at the five original release sites. Parasitization on three of those rose to the 40- to 60-percent range over the period 1960-70 and apparently was responsible for significant reductions in densities of larch casebearer (Denton 1972). At the other two original release sites, however, *A. pumila*, although persisting, was building up at a much slower rate. *A. pumila* appears to suffer considerable mortality in the teneral adult stage before it emerges from the host case under conditions of low relative humidity, which may help explain the difference in its performance between sites.

In recent years, we have expanded our parasite introduction program to include other species to supplement the action of *A. pumila*, starting with the release of *Chrysocharis laricinellae* (Ratz.) and *Dicladocerus westwoodii* Westw. in 1972 (Ryan and Denton 1973). In 1974, four other species were released: *Necremnus metalarus* (Walk.), *Elachertus argissa* (Walk.), *Dicladocerus japonicus* Yoshimoto,[1/] and *Diadegma laricinella* (Strobl) (Ryan et al. 1975). In 1975 and 1976 we released additional numbers of some of these species on new sites and on some old sites. The purpose of this paper is to document these additional releases.

[1/] This species was previously referred to as *Dicladocerus "A"* (Ryan et al. 1975) but was recently described by Yoshimoto (1976).

ACQUISITION, IDENTITY, AND RELEASE OF PARASITES

Details of the releases are summarized in table 1. Many of the releases reported here were from laboratory cultures derived from sources previously reported (Ryan et al. 1975). Sources are identifiable from the footnotes in table 1. Collections were made for several consecutive years in central Europe and in Japan. As this new genetic material became available, it was incorporated into the laboratory cultures to help offset any genetic deterioration unavoidably associated with laboratory propagation (Mackauer 1976).

A significant new collection was some additional *Dicladocerus japonicus* from a more northerly latitude, Shintoku and Shikoai, Hokkaido, Japan, by Dr. Paul Schaefer of the Asian Parasite Laboratory. Also, additional genetic stock of *Agathis pumila* obtained from Wisconsin was released, as was additional *A. pumila* material directly from Europe. Previously, all *A. pumila* material released in the Western United States was from stock already established in the Northeastern States. Many of the *A. pumila* released in the newer infestations in Oregon were, however, adults reared from previous colonization sites in Idaho and Montana.

Incoming exotic material was received at the Beneficial Insect Research Laboratory Quarantine facility at Newark, Delaware. Identifications were made by Drs. Gordon Gordh and P. M. Marsh of the U.S. National Museum.

Table 1--Releases of *Elachertus argissa*, *Necremnus metalarus*, *Chrysocharis laricinellae*, *Dicladocerus westwoodii*, and *Dicladocerus japonicus* in Idaho, Montana, Washington, and Oregon, 1975-76, and *Agathis pumila*, 1971-76

Locality	Date of release	Number released		
		Male	Female	Total
Elachertus argissa (Walker)[1/] (Hymenoptera: Eulophidae)				
Idaho:				
Bob's Creek and Potlatch Creek	June 11, 1975	87	616	703
46°51'N 116°20'W, T41N R1E S33				
Meadow Creek	June 11, 1975	111	616	727
46°36'N 115°55'W, T38N R4E S11				
Felton Creek	June 20, 1975	84	616	700
46°48'N 116°50'W, T40N R4W S20	Sept. 30, 1976	3	5	8
1 km N Troy Reservoir	June 20, 1975	50	200	250
46°49'N 116°47'W, T40N R4W S14				
Four Corners	May 21, 1976	30	123	153
48°17'N 116°59'W, T57N R5W S17				
Squaw Valley	May 21, 1976	25	124	149
48°27'N 116°56'W, T59N R5W S14	Sept. 23, 1976	19	34	53
Hanna Flats, 1 km W Priest Lake Ranger Stn.	May 21, 1976	30	123	153
48°34'N 116°56'W, T60N R5W S10				
Montana:				
6 km N Evaro	May 30, 1975	36	365	401
47°05'N 114°04'W, T15N R20W S1	Sept. 27, 1976	11	34	45
Washington:				
Colville Indian Reservation, E Round Lake	May 28, 1975	35	357	392
48°17'N 118°18'W, T32N R36E S8	Sept. 21, 1976	21	34	55
Charley Creek, 26 km S Pomeroy	May 29, 1975	42	358	400
46°15'N 117°30'W, T9N R42E S24				
Oregon:				
20 km N Elgin (BCC plot 6[2/])	May 28, 1975	11	105	116
45°44'N 117°55'W, T3N R39E S15	Oct. 9, 1975	18	197	215
	Oct. 10, 1975	21	125	146
	Oct. 15, 1975	32	153	185
22 km NNE Elgin (BCC plot 5)	May 28, 1975	11	101	112
45°45'N 117°50'W, T3N R40E S9	Sept. 18, 1975	11	21	32
	Sept. 23, 1976	21	41	62
25 km NE Elgin (BCC plot 4)	May 28, 1975	7	88	95
45°42'N 117°40'W, T3N R41E S35				
14 km SE Elgin (BCC plot 10)	Sept. 9, 1975	6	79	85
45°30'N 117°47'W, T1S R40E S11				
13 km SE Elgin (BCC plot 9)	Sept. 9, 1975	9	84	93
45°29'N 117°50'W, T1S R40E S17				
12 km SSE Elgin (BCC plot 8)	Sept. 9, 1975	11	76	87
45°28'N 117°51'W, T1S R40E S19				
15 km SSE Elgin (BCC plot 7)	Sept. 9, 1975	10	79	89
45°26'N 117°52'W, T1S R39E S36				
Necremnus metalarus (Walker)[1/] (Hymenoptera: Eulophidae)				
Idaho:				
Bob's Creek and Potlatch Creek	June 11, 1975	1	53	54
46°51'N 116°20'W, T41N R1E S33	Sept. 25, 1975	7	487	494
Meadow Creek	June 11, 1975	0	58	58
46°36'N 115°55'W, T38N R4E S11	Sept. 26, 1975	14	485	499

See footnotes at end of table.

Continued

Table 1--Releases of *Elachertus argissa*, *Necremnus metalarus*, *Chrysocharis laricinellae*, *Dicladocerus westwoodii*, and *Dicladocerus japonicus* in Idaho, Montana, Washington, and Oregon, 1975-76, and *Agathis pumila*, 1971-76--*Continued*

Locality	Date of release	Number released		
		Male	Female	Total
Idaho (continued):				
Felton Creek	June 20, 1975	0	54	54
46°48'N 116°50'W, T40N R4W S20	Sept. 25, 1975	11	487	498
	Sept. 30, 1976	28	48	76
Hanna Flats, 1 km W Priest Lake Ranger Stn.	Oct. 2, 1975	7	465	472
48°34'N 116°56'W, T60N R5W S10	May 21, 1976	1	32	33
Squaw Valley	Oct. 2, 1975	19	465	484
48°27'N 116°56'W, T59N R5W S14	May 21, 1976	3	33	36
	Sept. 23, 1976	2	30	32
Four Corners	Oct. 2, 1975	11	510	521
48°17'N 116°59'W, T57N R5W S17	May 21, 1976	2	33	35
Montana:				
6 km N Evaro	Sept. 26, 1975	2	363	365
47°05'N 114°04'W, T15N R20W S1	Sept. 27, 1976	2	33	35
Washington:				
Colville Indian Reservation, E Round Lake	Sept. 24, 1975	2	326	328
48°17'N 118°18'W, T32N R36E S8	Sept. 21, 1976	1	33	34
Charley Creek, 26 km S Pomeroy	Sept. 30, 1975	8	564	572
46°15'N 117°30'W, T9N R42E S24				
Oregon:				
20 km N Elgin (BCC plot 6)	May 28, 1975	2	36	38
45°45'N 117°55'W, T3N R39E S15	Oct. 9, 1975	0	331	331
	Oct. 10, 1975	0	56	56
	Oct. 15, 1975	0	76	76
22 km NNE Elgin (BCC plot 5)	May 28, 1975	3	36	39
45°45'N 117°50'W, T3N R40E S9	Sept. 18, 1975	3	124	127
	Sept. 23, 1975	2	307	309
	Sept. 29, 1975	9	521	530
	Oct. 2, 1975	18	873	891
	May 30, 1976	0	42	42
	Sept. 23, 1976	27	50	77
25 km NE Elgin (BCC plot 4)	May 28, 1975	6	34	40
45°42'N 117°40'W, T3N R41E S35				
14 km SE Elgin (BCC plot 10)	Sept. 9, 1975	5	64	69
45°30'N 117°47'W, T1S R40E S11				
13 km SE Elgin (BCC plot 9)	Sept. 9, 1975	7	57	64
45°29'N 117°50'W, T1S R40E S17				
12 km SSE Elgin (BCC plot 8)	Sept. 9, 1975	10	58	68
45°28'N 117°51'W, T1S R40E S19				
15 km SSE Elgin (BCC plot 7)	Sept. 9, 1975	7	59	66
45°26'N 117°52'W, T1S R39E S36				
Chrysocharis laricinellae (Ratz.) (Hymenoptera: Eulophidae)				
Idaho:[1/]				
Four Corners	Sept. 23, 1976	85	26	111
48°17'N 116°59'W, T57N R5W S17				
Squaw Valley	Sept. 23, 1976	85	26	111
48°27'N 116°56'W, T59N R5W S14				

See footnotes at end of table.

Continued

Table 1--Releases of *Elachertus argissa*, *Necremnus metalarus*, *Chrysocharis laricinellae*, *Dicladocerus westwoodii*, and *Dicladocerus japonicus* in Idaho, Montana, Washington, and Oregon, 1975-76, and *Agathis pumila*, 1971-76--*Continued*

Locality	Date of release	Number released		
		Male	Female	Total
Idaho (continued):				
Hanna Flats, 1 km W Priest Lake Ranger Stn. 48°34'N 116°56'W, T60N R5W S10	Sept. 23, 1976	85	26	111
Felton Creek 46°48'N 116°50'W, T40N R4W S20	Sept. 30, 1976	200	74	274
Oregon:[3/]				
26 km NE Elgin (BCC plot 3)	May 28, 1975	491	307	798
45°42'N 117°39'W, T3N R41E S35	June 4, 1975	524	488	1012
	Sept. 23, 1975	284	124	408
22 km NNE Elgin (BCC plot 5)	May 19, 1976	368	328	696
45°45'N 117°50'W, T3N R40E S9	Sept. 23, 1976	342	145	487
	Sept. 29, 1976	393	74	467
	Oct. 7, 1976	268	69	337
Dicladocerus westwoodii Westw.[1/] (Hymenoptera: Eulophidae)				
Idaho:				
Benton Creek, Priest River Exp. For.	May 20, 1976	117	46	163
48°21'N 116°50'W, T58N R4W S26	Sept. 22, 1976	105	39	144
	Oct. 8, 1976	278	155	433
Dicladocerus japonicus Yoshimoto[4/] (Hymenoptera: Eulophidae)				
Idaho:				
1 km N Troy Reservoir	June 20, 1975	258	285	543
46°49'N 116°48'W, T40N R4W S14				
Four Corners	May 21, 1976	52	40	92
48°17'N 116°59'W, T57N R5W S17				
Hanna Flats, 1 km W Priest Lake Ranger Stn.	May 21, 1976	52	40	92
48°34'N 116°56'W, T60N R5W S10				
Squaw Valley	May 21, 1976	53	41	94
48°27'N 116°56'W, T59N R5W S14				
Moscow Mt., 7 km N Troy	June 4, 1976	34	54	88
46°47'N 116°48'W, T40N R4W S23				
Oregon:				
22 km NNE Elgin (BCC plot 5)	May 30, 1976	78	102	180
45°45'N 117°50'W, T3N R40E S9	Sept. 23, 1976	72	280	352
	Oct. 7, 1976	237	146	383
Agathis pumila (Ratz.) (Hymenoptera: Braconidae)				
Washington:				
Charley Creek, 26 km S Pomeroy	July 10, 1971[5/]	73	14	87
46°15'N 117°30'W, T9N R42E S24	July 19, 1971[5/]	31	122	153
	July 7, 1973 [1/]	91	111	202
	July 7, 1973 [6/]	131	222	353
Oregon:				
Emigrant Springs, 27 km ESE Pendleton[5/]	July 12, 1971	85	14	99
45°33'N 118°28'W, T1N R35E S20	July 19, 1971	38	113	151
	July 20, 1972	30	38	68
	July 14, 1973	341	333	674
	July 20, 1973	10	106	116

See footnotes at end of table.

Continued

Table 1--Releases of *Elachertus argissa*, *Necremnus metalarus*, *Chrysocharis laricinellae*, *Dicladocerus westwoodii*, and *Dicladocerus japonicus* in Idaho, Montana, Washington, and Oregon, 1975-76, and *Agathis pumila*, 1971-76--*Continued*

Locality	Date of release	Number released		
		Male	Female	Total
Oregon (continued):				
Hwy 204, 14 km E Weston	Aug. 20, 1974[6/]	34	21	55
45°48'N 118°14'W, T4N R37E S30	Aug. 28, 1974[6/]	10	7	17
	July 7, 1975[1/]	340	222	562
	July 14, 1975[1/]	11	74	85
26 km NE Elgin (BCC plot 3)[5/]				
45°42'N 117°39'W, T3N R41E S35	Aug. 20, 1975	24	300	324
	Aug. 25, 1975	6	300	306
25 km NE Elgin (BCC plot 4)[5/]	Aug. 20, 1975	24	300	324
45°42'N 117°40'W, T3N R41E S35	Aug. 25, 1975	8	400	408
22 km NNE Elgin (BCC plot 5)				
45°45'N 117°50'W, T3N R40E S9	Aug. 20, 1975[5/]	24	300	324
	Aug. 21, 1975[5/]	15	300	315
	Aug. 25, 1975[5/]	4	200	204
	July 6, 1976[1/]	40	87	127
20 km N Elgin (BCC plot 6)[5/]	Aug. 21, 1975	15	300	315
45°44'N 117°55'W, T3N R39E S15	Aug. 25, 1975	6	300	306
15 km SSE Elgin (BCC plot 7)[5/]	July 29, 1975	66	141	207
45°26'N 117°52'W, T1S R39E S36	Aug. 21, 1975	24	300	324
	Aug. 22, 1975	6	300	306
	Aug. 26, 1975	1	200	201
	Aug. 27, 1975	0	4	4
12 km SSE Elgin (BCC plot 8)[5/]	Aug. 15, 1975	100	100	200
45°28'N 117°51W, T1S R40E S19	Aug. 20, 1975	24	300	324
	Aug. 22, 1975	6	300	306
	Aug. 26, 1975	0	100	100
	July 4, 1976	1	10	11
	July 6, 1976	30	30	60
	July 8, 1976	100	100	200
	July 12, 1976	20	80	100
	July 14, 1976	40	200	240
	July 19, 1976	0	106	106
13 km SE Elgin (BCC plot 9)[5/]	Aug. 20, 1975	24	300	324
45°29'N 117°50'W, T1S R40E S17	Aug. 22, 1975	6	300	306
	Aug. 26, 1975	2	100	102
	Aug. 28, 1975	0	52	52
	July 12, 1976	75	300	375
	July 16, 1976	10	122	132
14 km SE Elgin (BCC plot 10)[5/]	Aug. 20, 1975	24	300	324
45°30'N 117°47'W, T1S R40E S11	Aug. 21, 1975	15	300	315
	Aug. 22, 1975	6	300	306

[1/] Parasite strain originated in Austria-northern Italy.

[2/] Boise Cascade Corp. plot number.

[3/] Parasite strain originated in Sweden.

[4/] Parasite strain originated in Japan.

[5/] Parasite strain recolonized from Idaho-Montana.

[6/] Parasite strain recolonized from Wisconsin.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

3.79 PNW-291

PNW-291

February 1977

UREA FERTILIZER INCREASES GROWTH OF 20-YEAR-OLD, THINNED DOUGLAS-FIR ON A POOR QUALITY SITE

MAY 16 1977 SOIL TECH. & AGR. DIV.

by

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and

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ABSTRACT

In 20-year-old, site V Douglas-fir in southwest Washington, fertilizing with nitrogen increased average 5-year diameter and height growth of concurrently released dominant trees by about 85 percent. There was no additional response when phosphorus, potassium, and sulfur were added with the nitrogen fertilizer. Thinning with no other treatment in this moderately stocked plantation did not increase 5-year diameter growth, and it reduced height growth by about 25 percent. Although this reduced height growth will probably be offset by increased growth in the future, managers of nitrogen deficient sites should consider fertilizing shortly before or after thinning to accelerate response to release.

KEYWORDS: Fertilizer response (forest tree), increment (height), increment (diameter), nitrogen fertilizer response, urea, site class, thinning (tree).

In spring 1970, we fertilized individual, dominant Douglas-fir trees in a recently thinned stand on the Wind River Experimental Forest in southwest Washington. We report the 5-year results from this simple field trial to inform local land managers and to augment information collected from more comprehensive trials on other soils and for other stand conditions.

METHODS

The site V stand is located on Soil 44, a moderately deep, sandy loam derived from ash and pumice.[1/] Slope gradient is about 10 percent, aspect easterly; elevation is about 2,100 feet.[2/] The stand was planted in spring 1952, at approximately 8- by 8-foot spacing, following clear-cutting of old growth. Supplemented with natural fill-in, the plantation subsequently developed a clumpy distribution of groups of trees intermingled with openings where trees had not survived. After the 1969 growing season, when the planted trees were 20 years old from seed, the stand contained about 500 trees per acre, with trees averaging about 2.9 inches in d.b.h. and 20 feet in height.

Prior to precommercial thinning in March 1970, we installed two adjacent 1/5-acre plots (fig. 1). One plot plus a 27-foot-wide buffer

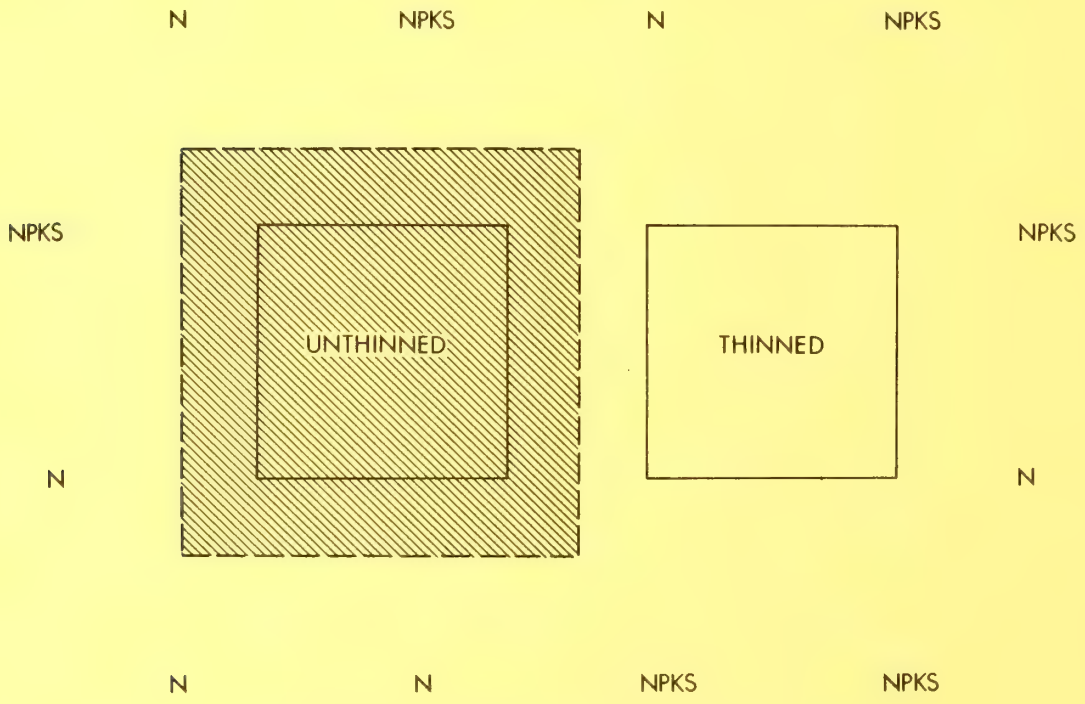

Figure 1.--Layout of study area.

[1/] U.S. Forest Service, Gifford Pinchot National Forest. [n.d.]. Soil resources atlas of maps and interpretive tables. 31 p., illus. Vancouver, Wash.

[2/] Metric conversions: inches X 2.54 = centimeters; feet X 0.304 = meters; square feet X 0.093 = square meters; acres X 0.405 = hectares; pounds per acre X 1.12 = kilograms per hectare.

was left unthinned. Thinning of the other plot and surrounding portion of the stand removed 34 percent of the trees (155 trees per acre) and 20 percent of the basal area (table 1). Trees had not yet attained a large enough size to be strongly competitive, so the thinning was not expected to have much immediate effect on growth.

Table 1--*Stand characteristics of 20-year-old trees on two 1/5-acre plots, Wind River Experimental Forest, Washington*

(Per-acre basis)

D.b.h. class	Unthinned plot[1/]	Thinned plot[2/]		
		Before thinning	Cut	After thinning
Inches	- - - - - - - Number of trees - - - - - - -			
1	65	25	15	10
2	185	150	95	55
3	195	195	45	150
4	110	70	0	70
5	5	10	0	10
6	5	0	0	0
Total	565	450	155	295
Basal area, square feet	25.2	20.4	4.4	16.1
Average d.b.h., inches	2.9	2.9	2.3	3.2

[1/] Site index (100-year base), 80.

[2/] Site index (100-year base), 77.

For assessing response to fertilization, we selected 12 dominant trees within the thinned portion of the stand immediately surrounding the plots (fig. 2). After random assignment of treatment, six of these

Figure 2.--A fertilized sample tree in the pre-commercially thinned plantation.

trees were fertilized in April 1970 with 300 pounds of elemental nitrogen (N) per acre as urea; the other six were fertilized with the same fertilizer and dosage, but with additional fertilizers to provide phosphorus (P), potassium (K), and sulfur (S) (table 2). Fertilizer was spread on a 1/40-acre area (18.6-foot radius) around each tree to insure fertilization of competing trees.

Table 2--*Fertilization treatments of 12 trees in a thinned portion of a stand, Wind River Experimental Forest, Washington*

Treatment	Elemental				Source	Analysis
	N	P	K	S		
	--Pounds per acre[1/]--					
Thinning plus N (6 trees)	300	0	0	0	Urea	46-0-0-0
Thinning plus N, P, K, and S (6 trees)	300	0	0	0	Urea	46-0-0-0
	0	42	0	50	Golden treble superphosphate	0-38-0-20
	0	108	0	0	Treble superphosphate	0-45-0-0
	0	0	100	0	Potassium chloride	0-0-60-0

[1/] Pounds per acre X 1.12 = kilograms per hectare.

Our fertilizer treatments were based on prior chemical analysis of current foliage composited from four dominant trees on each plot. In October 1969, the nitrogen content of 1969 foliage averaged 0.91 percent for the plot selected for thinning and 1.03 percent for the one to be left unthinned; this strongly suggested nitrogen deficiency. Chemical analyses also suggested deficiencies of P and K.

Five years after treatment, we compared height and diameter growth of the 12 fertilized trees (6 per treatment) with growth of 6 trees each on the unfertilized thinned and unthinned plots. These plot trees were matched by d.b.h. to the fertilized trees, but not by other tree characteristics in the field.[3/]

[3/] Although the unfertilized trees were grouped and thus not located on a completely random basis, data were analyzed as a completely random design. Treatment means were adjusted by covariance for initial differences in tree size and then tested in three orthogonal comparisons to contrast the average growth of untreated vs. treated, thinning vs. thinning and fertilizing, and fertilizing with N vs. N, P, K, and S. A 5-percent probability of a Type I error ($P<0.05$) was accepted as statistically significant.

RESULTS AND DISCUSSION

Crown and Needle Changes

Color and length of needles improved markedly in fertilized trees in the first growing season. Although we did not repeat our foliar analysis to measure changes in chemical content of foliage, we observed that darker green foliage and longer lateral branch growth persisted for at least three growing seasons.

Diameter Growth

During the 5 years after treatment, average diameter growth of fertilized (and thinned) trees was about 85 percent greater than that of their thinned-only counterparts (table 3). Average diameter growth did not differ significantly between trees receiving the N or the NPKS

Table 3--*Average diameter and annual growth of sample trees by treatment, Wind River Experimental Forest, Washington*

Treatment[2/]	Quadratic mean d.b.h.		Average annual growth[1/]	
	1969	1974	Absolute	Relative to thinned only
	- - - - - Inches- - - - -			Percent
Untreated	3.9	5.1	0.23	104
Thinning	3.6	4.7	.22	100
Thinning plus N	4.1	6.2	.42	191
Thinning plus N, P, K, and S	3.7	5.7	.40	182

[1/] Treatment means adjusted by covariance to a common, pretreatment d.b.h.

[2/] See table 2 for amounts of fertilizer and source.

treatment. Among the unfertilized trees (untreated or thinned-only), diameter growth was significantly correlated with initial d.b.h.; larger trees grew more than smaller trees. A lack of correlation among the fertilized trees (r=0.02 and 0.04) apparently resulted from more variable diameter growth among fertilized trees and from smaller trees growing about the same as larger trees.

Thinning evidently did not improve diameter growth during the first 5 years after thinning. Growth of thinned trees was similar to growth of untreated trees (table 3); moreover, relative radial growth for the 5-year period before and after thinning did not differ in a subsample of increment cores from both plots. We assume that this lack of initial response is explained by the relatively low intensity of competition before thinning. Despite limited thinning and release, however, "thinning shock" may have contributed to lack of response.

Height Growth

Fertilized-and-thinned dominant trees averaged about twice as much height growth as thinned-only dominants during the 5 years after treatment (table 4). Average height growth did not differ significantly

Table 4--*Average height and annual growth of sample trees by treatment, Wind River Experimental Forest, Washington*

Treatment	Mean height		Average annual growth[1/]	
	1969	1974	Absolute	Relative to thinned only
	- - - - - Feet - - - - -			Percent
Untreated	24.0	31.6	1.51	157
Thinning	21.1	25.9	.96	100
Thinning plus N	23.9	34.6	2.13	222
Thinning plus N, P, K, and S	20.5	31.0	2.11	220

[1/] Treatment means adjusted by covariance to a common, pretreatment height.

between dominants receiving the N or the NPKS treatment. Height growth was not correlated with initial height among the untreated, thinned-only, and thinned plus NPKS trees. In contrast, height growth of trees fertilized with N was correlated with initial height ($P<0.001$); shorter trees apparently responded more to this fertilization than did taller trees. The absence of a corresponding statistically significant correlation among trees additionally fertilized with PKS was due to greater variation in height growth among these trees than among those fertilized with N alone. Depressed height growth on two trees with unusually heavy cone crops contributed strongly to this variation. These two trees had the least height growth of the six-tree sample and produced about 20 and 40 cones in 1971 (year 2) and 0 and 50 cones in 1974 (year 5) compared with 0 to 3 cones in the remaining trees in the same years.

At other locations, nitrogen fertilizer improved height growth of site IV and V Douglas-fir in the sapling-to-small-pole stage on soils developing from glacial materials of the Puget Sound lowlands (Gessel and Walker 1956, Crossin et al. 1966) and on soils developing from pyroclastics within a few miles of this study area (Miller and Pienaar 1973). In the latter area, the 7-year improvement in height growth with 280 pounds of N per acre as ammonium nitrate averaged 76 percent for all crown classes in an unthinned plantation.

During the 5 years after thinning, height growth of the six-tree sample in the thinned plot averaged 36 percent less than that of its counterpart in the unthinned plot (table 4). We were concerned about the representativeness of this sample, because it included several trees

with unusually small, prethinning height growth. Thus, our small sample could have overestimated the actual reduction caused by thinning. Our concern was substantiated by comparisons of all trees measured for height in the two plots (15 trees per plot), which used either initial height or 3-year pretreatment height growth as a covariate. Both analyses indicated that thinning significantly reduced height growth by about 25 percent instead of 36 percent. If this lesser reduction in height growth after thinning is assumed, fertilizing the thinned stand increased height growth by about 84 percent rather than 120 percent.

Others have also reported reductions in Douglas-fir height growth in initial years after precommercial thinning on poor sites (Staebler 1956, Williamson 1976). In the latter report, height growth of dominant trees released by thinning was less than that of their counterparts in an unthinned portion of the stand; however, this was reversed in years 3 through 6. As reported by Staebler (1956), thinning a 25-year-old plantation to densities ranging from 50 to 350 trees per acre reduced growth about 50 percent during the first 2 years. Height growth of released trees began exceeding control growth about 10 years after thinning.[4/] Thus, previously reported reductions in height growth after precommercial thinning have been of short duration and have been compensated for by subsequent improvement in height growth.

CONCLUSIONS

1. Fertilizing a concurrently thinned, site V stand clearly improved diameter and height growth of dominant trees. Compared with thinned-only trees, thinned-and-fertilized trees grew about 85 percent more in diameter and height.

2. There was no additional response when P, K, and S were added with the nitrogen fertilizer.

3. During the 5-year period after thinning with no other treatment, diameter growth in this moderately stocked plantation did not increase and height growth was reduced by about 25 percent. Although this reduction will probably be offset by increased growth in the future, managers of nitrogen-deficient sites should consider fertilizing shortly before or after thinning to accelerate response to release.

4. This field trial strongly suggests that similar stands on Soil 44 and related soils of the Gifford Pinchot National Forest are likely candidates for operational fertilization with nitrogen. Based on this and other field trials, our recommendation is 200 pounds of nitrogen per acre as either urea or ammonium nitrate.

[4/] Unpublished data on file at the Forestry Sciences Laboratory, Olympia, Washington.

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-292

March 1977

WETLINE TECHNIQUE FOR PRESCRIBED BURNING FIRELINES IN RANGELAND

by

Robert E. Martin, Stuart E. Coleman, and Arlen H. Johnson[1/]

SEP 0 1977

Abstract

Backpack pumps or pickup pumpers and two 4-foot wands attached to a Y can be used to install firelines for prescribed burning in light fuels on rangeland. The technique is inexpensive, effective, and it does not permanently deface the landscape.

KEYWORDS: Fireline construction, firelines, prescribed burning, range management.

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Building firelines for prescribed burning can be expensive, time consuming, and often damaging to the landscape. The technique described here is rapid, low cost, and does not permanently disturb the landscape. It is applicable primarily for range and light shrub fuels and could also be used in fire control activities.

Many prescribed burning projects are not undertaken because of the cost of line construction. Further, conventional line-building techniques cannot be used in some situations; our wetline technique may work well in the same situations.

Our techniques are not necessarily new. A similar technique, using fire retardants and high pressure spraying equipment, has been developed at Wind Cave National Park.[2/] The difference between the two techniques is that we use standard firefighting equipment and plain water and then burn out an adjacent area. The Wind Cave technique can treat more line per volume of liquid and may or may not involve immediate burnout.

The Technique

We have used three variations in developing the technique (fig. 1). Of the three, we prefer the method of two double wetlines (fig. 1C) where

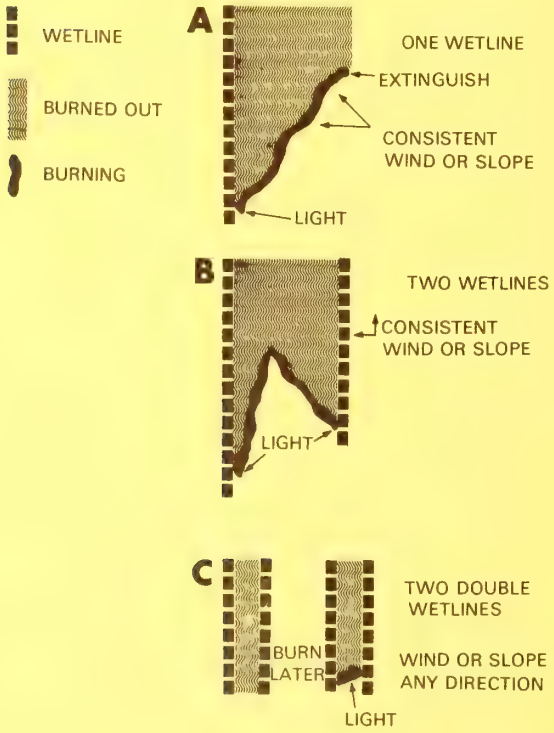

Figure 1.--Three variations of the wetline technique. Wetlines are 1 to 2 feet (0.3 to 0.6 meter) wide. Double wetlines are 6 to 8 feet (1.8 to 2.5 m) apart, and burnout areas generally 20 to 50 feet (6 to 15 m) wide.

2/ Shilts, D. 1975. Use of chemical fire retardants at Wind Cave National Park. 3 p., mimeogr.

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Figure 2.--Fireline being established by one wetline. The wetline is applied to the left and the fire allowed to back away. The burner is lighting some unburned fuel after the backing fire was extinguished.

vehicle access permits its use. The first variation (fig. 1A and fig. 2) involves backfiring from one wetline. Once a sufficient width of line has burned out, the backfire is extinguished with more water or tools such as fire flaps or rakes. A consistent wind or slope is necessary. We have used the technique only under moderate burning conditions. As can be seen from figure 1A, the fire is not contained on one side and one end, presenting a degree of risk. We have used this method in the evening when strip headfires would burn into the wetline, but the backfire would go out.

The second variation (fig. 1B and fig. 3) involves running two parallel wetlines some distance apart and burning out the fuel between the two lines. The wetlines may be applied with backpack pumps or vehicle-mounted units. We use one burner with each wetline. When wind is from one side of the line, the downwind line should be burned out ahead of the upwind line. Again, consistent winds are necessary. One end of the fire is not contained during burnout.

The method of two double wetlines (fig. 1C) is probably most applicable where terrain permits use of vehicles. Two 4-foot (1.2-m) wands with spray heads are attached to a Y on a single fire hose (fig. 4). At the beginning of a line, the spray equipment is swung back and forth to seal off the end of the line. The vehicle then moves forward, laying two parallel wetlines 1 to 2 feet (0.3-0.6 m) wide and 6 to 8 feet (1.8-2.5 m) apart. The burner follows behind the vehicle, burning out the intervening fuel (fig. 5). A second strip may be burned some distance away, and a wider area between the two strips is then burned out. Wind direction is not critical in this variation. If the fire runs too rapidly toward the

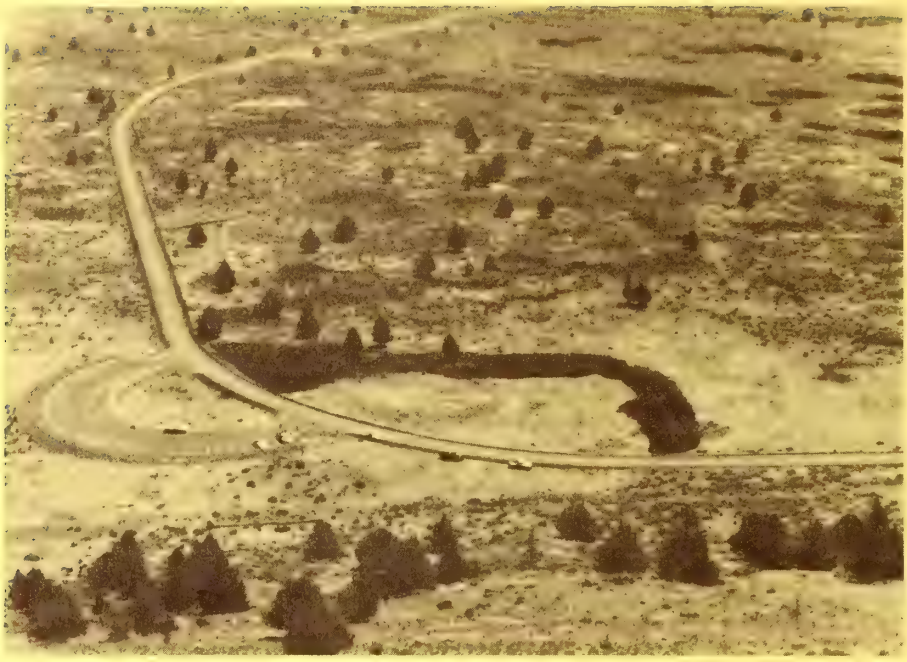

Figure 3.--View of a fireline formed around a small plot by the two-wetline method (fig. 1B). Line width variation resulted from forming line around terrain and fuel concentrations. The parking lot on left is a prime historical location and lines permanently disturbing the landscape would be unacceptable.

Figure 4.--Spray from the double wands on Y has just sealed off end of line; hose was pulled from reel to reach area inaccessible to truck; hose will be reeled in as torch man burns out fuel between double wetlines.

Figure 5.--Truck with pump operator moves through cheatgrass range as torch man burns out intervening fuels.

vehicle, the spray operator can stop the advance by a sidewise movement of the wands.

When it is necessary to install a wetline up to several hundred feet from an area accessible to a vehicle, we pull hose from the reel, then use the reel motor to pull the hose in while the double wands are used to apply the wetline.

Application

We have used only the third variation to develop long wetlines. Using No. 3 sprayer heads with 100 psi pressure at the pump, we built 1.1 miles (1.8 km) of fireline in 25 minutes at a rate of about 2.6 miles (4.2 km) per hour. Approximately 175 gallons (662 liters) of water were used, or about 160 gallons per mile (376 liters/km). We have used the technique in a variety of range burning situations. The lines, however, have generally been short because we utilized terrain and roads for most of the firelines. Burning conditions have ranged from 20 to 35 percent relative humidity, 60 to 80 ^{O}F (15 to 27 ^{O}C) and winds to 10 miles (16 km) per hour.

Limitations

We have used this technique only for burning ranges where no heavy litter and duff are present. Since the water is applied over a very short time period, heavy litter and duff are not wetted deeply. Also, the burnout time for heavy litter and duff is too long for the temporary wetline to contain. Before the prescribed burn is ignited, the burned out line should be tested to be sure fire cannot creep through it.

Undoubtedly the technique could be made more efficient through equipment modification and an evaluation of the amount of water needed. We feel the technique is sufficiently developed, particularly the method of two double wetlines, to be useful to land managers.

With use of this technique, as with any prescribed burning, these steps should be followed:

(1) Weather forecasts and fire agencies should be checked before burning is started.

(2) Firelines should be scouted and marked before line construction is begun.

(3) Burned out wetline should be checked and tested before prescribed burning is started.

(4) Weather should agree with forecast and the prescription.

(5) Adequate backup personnel should be available in case of trouble.

* * * * *

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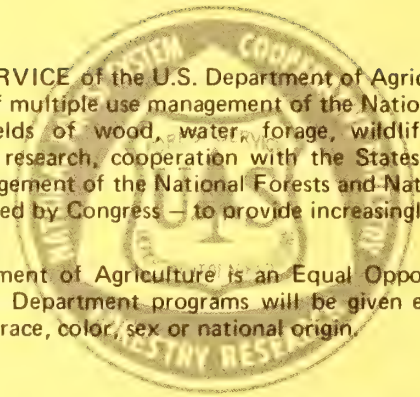

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FINANCIAL CONSEQUENCES OF COMMERCIAL THINNING REGIMES IN YOUNG-GROWTH DOUGLAS-FIR

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by

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ABSTRACT

Commercial thinning in fully-stocked normal Douglas-fir stands of merchantable size is evaluated and compared to the alternatives of leaving stands to grow unthinned or of liquidating them. Comparisons are made in terms of volume production and financial returns.

KEYWORDS: Thinning (commercial), economic evaluation, young-growth stands, Douglas-fir.

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The tables contained in this note show the financial returns that can be expected from given regimes of commercial thinning in young-growth Douglas-fir stands of merchantable size. The stands evaluated are fully stocked and have not been precommercially thinned. The audiences for this note are forest owners and managers who are faced with the decision of what to do with existing merchantable stands of Douglas-fir. Should the stands be thinned, allowed to grow further without thinning, or immediately harvested?

The decision criteria used are strictly financial. Each stand is evaluated independently on a per acre basis. This means that the possible effects of stand treatment on allowable cut quotas for entire forests are ignored.

Data and Thinning Assumptions

In order to determine the financial consequences of thinning Douglas-fir, data had to be obtained on the yield response of stands to thinning and the performance of unthinned stands. Both types of data have been developed from the results of studies across the Douglas-fir region of the growth patterns of thinned and unthinned Douglas-fir stands. The means for generating these data are available from the DFIT (Douglas-fir Interim Table) program.[1/] The DFIT program is a stand simulator containing growth equations and many assumptions about management practices and their effect on stand development. The assumptions are based on data representing currently available information on the thinning of Douglas-fir and on the growth and yield of unmanaged stands. A publication in which the assumptions are discussed is also being prepared.[2/]

For this paper the prediction of yields from thinning is based on several important assumptions concerning the condition of stands and the way thinning is done. These assumptions follow:

1. At time of initial thinning, stands are "normal" by DFIT standards--in terms of number of trees, average d.b.h., and volume per acre. This approximates Bulletin 201.[3/]

2. Yield data are based on fully stocked acres. No deductions are made for insect and disease losses nor for nonproductive features such as roads, landings, or skidroads.

3. Commercial thinning is first feasible when average d.b.h. of cut trees is about 9 inches (22.9 cm).

4. Commercial thinning is regarded as a regime, i.e., a series of thinning entries, applied to a stand. The regime consists of an initial thinning followed by subsequent thinnings, the last being no closer to final harvest than 10 years. Intervals between thinnings are generally 10 years except for lower site classes where the interval is longer to allow the stand to build thinning volume in excess of 1,000 cubic feet per acre (70 cubic meters per hectare) (4-inch (10.2 cm) top), the assumed minimum volume needed to conduct a commercial thinning operation.

5. Thinnings reduce the merchantable basal area to the greater of two-thirds of prethinning basal area or to a level which varies by average diameter of merchantable trees, ranging from 51 percent for 10-inch (25.4-cm) d.b.h. to 63 percent for 30-inch (76.2-cm) d.b.h.

6. Average d.b.h. of cut trees (d) relative to average d.b.h. of merchantable trees before thinning (D) varies with age. Maximum d/D is 1.0 at the first possible commercial thinning. Minimum d/D is 0.8.

These assumptions were used in developing commercial thinning yields. The cubic-foot (4-inch (10.2-cm) top) and Scribner (6-inch (15.2-cm) top)[4/] volume gains resulting from thinning are shown in table 1.

[1/] Bruce, David, Donald J. Demars, and Donald L. Reukema. "Douglas-fir managed yield simulator: DFIT user's guide." Unpublished.

[2/] Reukema, Donald L., and David Bruce. Effects of thinning on yield of Douglas-fir; concepts and some estimates obtained by simulation. Unpublished.

[3/] McArdle, Richard E., Walter H. Meyer, and Donald Bruce. 1961. The yield of Douglas-fir in the Pacific Northwest. U.S. Dep. Agric. Tech. Bull. 201 (revised). 74 p., illus.

[4/] Based on scaling 16-foot (4.88-m) logs to nearest 0.1 inch (.25-cm) and using formula rule.

Table 1--*Change in volume yield expected from commercially thinned stands of Douglas-fir compared to yields from natural stands. Change is expressed in cubic feet*[1/] *(4-inch top) and Scribner board feet (6-inch top) and as a percentage of natural stand yields. Comparisons vary by age at initial thinning entry, rotation age, and site class*

SITE I (SITE INDEX 200)

Log rule	Rotation age	Volume yield of natural stand	Volume change of stand by age at initial thinning entry									
			30		40		50		60		70	
	Years	M ft/acre	M ft/acre	Percent	M ft/acre	Percent	M ft/acre	Percent	M ft/acre	Percent	M ft/acre	Percent
Cubic	80	18.3	2.7	15	2.6	14	2.1	11	1.4	8	0.6	3
	70	16.6	1.8	11	1.8	11	1.4	8	.7	4	--	--
	60	14.7	.9	6	.9	6	.6	4	--	--	--	--
	50	12.3	.1	1	.2	2	--	--	--	--	--	--
	40	9.1	-.3	-3	--	--	--	--	--	--	--	--
Scribner	80	118.4	9.2	8	8.4	7	7.6	6	5.5	5	2.7	2
	70	104.1	4.8	5	4.5	4	4.2	4	2.5	2	--	--
	60	87.2	.9	1	1.2	1	1.4	2	--	--	--	--
	50	67.0	-1.6	-2	-.8	-1	--	--	--	--	--	--
	40	42.8	-1.6	-4	--	--	--	--	--	--	--	--

[1/] Metric conversion: cubic feet per acre x .0700 = cubic meters per hectare.

SITE II (SITE INDEX 170)

Log rule	Rotation age	Volume yield of natural stand	Volume change of stand by age at initial thinning entry									
			35		45		55		65		75	
	Years	M ft/acre	M ft/acre	Percent	M ft/acre	Percent	M ft/acre	Percent	M ft/acre	Percent	M ft/acre	Percent
Cubic	85	15.2	1.7	11	1.7	11	1.4	9	1.0	7	0.4	3
	75	13.9	1.1	8	1.1	8	.9	6	.5	4	--	--
	65	12.4	.4	3	.5	4	.3	2	--	--	--	--
	55	10.5	-.1	-1	0	0	--	--	--	--	--	--
	45	7.9	-.2	-3	--	--	--	--	--	--	--	--
Scribner	85	93.2	4.6	5	4.1	4	4.0	4	3.0	3	1.7	2
	75	82.0	1.8	2	1.7	2	2.0	2	1.3	2	--	--
	65	69.0	-.5	-1	-.1	--	.4	1	--	--	--	--
	55	53.7	-1.8	-3	-1.0	-2	--	--	--	--	--	--
	45	35.6	-1.3	-4	--	--	--	--	--	--	--	--

SITE III (SITE INDEX 140)

Log rule	Rotation age	Volume yield of natural stand	Volume change of stand by age at initial thinning entry									
			45		55		65		75		85	
	Years	M ft/acre	M ft/acre	Percent	M ft/acre	Percent	M ft/acre	Percent	M ft/acre	Percent	M ft/acre	Percent
Cubic	95	12.5	1.0	8	1.0	8	0.9	7	0.5	4	0.2	2
	85	11.5	.6	5	.6	5	.5	4	.3	3	--	--
	75	10.4	.2	2	.3	3	.2	2	--	--	--	--
	65	9.2	-.2	-2	0	0	--	--	--	--	--	--
	55	7.4	-.2	-3	--	--	--	--	--	--	--	--
Scribner	95	70.8	1.4	2	1.5	2	1.5	2	1.2	2	.7	1
	85	63.0	0	0	.3	0	.6	1	.5	1	--	--
	75	54.2	-1.1	-2	-.5	-1	0	0	--	--	--	--
	65	43.9	-1.6	-4	-.7	-2	--	--	--	--	--	--
	55	32.0	-1.1	-3	--	--	--	--	--	--	--	--

SITE IV (SITE INDEX 110)

Log rule	Rotation age	Volume yield of natural stand	Volume change of stand by age at initial thinning entry									
			60		70		80		90		100	
	Years	M ft/acre	M ft/acre	Percent	M ft/acre	Percent	M ft/acre	Percent	M ft/acre	Percent	M ft/acre	Percent
Cubic	110	9.6	0.3	3	0.4	4	0.3	3	0.2	2	0.1	1
	100	9.0	.1	1	.2	2	.2	2	.1	1	--	--
	90	8.3	-.1	-1	0	0	0	0	--	--	--	--
	80	7.5	-.2	-3	-.1	-1	--	--	--	--	--	--
	70	6.4	-.2	-3	--	--	--	--	--	--	--	--
Scribner	110	48.8	-.8	-2	-.5	-1	-.2	0	0	0	.1	0
	100	44.1	-1.2	-3	-.7	-2	-.4	-1	0	0	--	--
	90	38.7	-1.4	-4	-.9	-2	-.2	-1	--	--	--	--
	80	32.7	-1.4	-4	-.6	-2	--	--	--	--	--	--
	70	25.8	-.8	-3	--	--	--	--	--	--	--	--

SITE V (SITE INDEX 80)

Log rule	Rotation age	Volume yield of natural stand	Volume change of stand by age at initial thinning entry			
			90		100	
	Years	M ft/acre	M ft/acre	Percent	M ft/acre	Percent
Cubic	110	5.7	-0.2	-4	-0.1	-2
	100	5.1	-.1	-2	--	--
Scribner	110	21.7	-1.0	-5	-.4	-2
	100	18.5	-.5	-3	--	--

Yield Results

Table 1 shows the changes in volume yield expected from commercially thinned stands compared to yields from natural stands. Differences in yields are shown as percentages and in cubic-foot (4-inch (10.2-cm) top) and Scribner (6-inch (15.2-cm) top) volumes. Alternative ages at which stands can be thinned for the first time are shown across the top of the table. Alternative rotation ages are shown down the left-hand side of the table. Five site class conditions are evaluated. Volume yields of natural stands grown to comparable rotation ages are given for purposes of comparison. The reader should keep in mind that where 20 or more years separate the initial entry from final harvest, more than one thinning entry is made. Table 2 contains a column showing total number of thinning entries that correspond to each combination of site class, rotation age, and age at initial entry.

The yield results were obtained from the DFIT program under the assumptions stated in the previous section. The yield results summarize volumes cut at each thinning and at final harvest. In addition, an allowance was made for salvaging merchantable mortality.

To use table 1, one needs to specify site class, age of stand to the nearest 10 years, and the proposed rotation age. For example, if the stand is on site II and is closest to age 45 with a proposed final harvest at age 65, the table shows that in terms of cubic feet, commercial thinning would produce 500 feet per acre (35 cubic meters per hectare) of additional volume or 4 percent more than a natural stand. In terms of Scribner log scale there would be a slight loss. The thinning regime imposed in this case would consist of the initial thinning at age 45 and an intermediate thinning 10 years later at age 55.

A number of observations drawn from the data shown in table 1 follow:

1. In terms of Scribner board-foot production, commercial thinning contributes little (5 percent or less) or reduces total output on sites II to V. This is also true for site I with the exception of rotations of 80 years.

2. In terms of cubic-foot production, commercial thinning contributes from 5 to 15 percent on sites I to III when thinning begins early and rotations are relatively long. In other cases, gains, if any, are less than 5 percent.

3. Stands entered early and held for relatively long rotations, especially on sites I to III, produce the largest volume gains from commercial thinning. Stands managed for shorter rotations and lower site stands produce the least volume and often result in losses. To reduce such losses, managers might thin later in the stand's life or reduce the number of thinnings or reduce the amount thinned, especially at the first thinning.

4. In terms of generating additional volume, commercial thinning on higher sites is clearly more productive than thinning on lower sites.

Financial Criteria and Assumptions

Table 1 presented the yield results of commercial thinning in Douglas-fir. In table 2 the same regimes and site conditions are evaluated using present value criteria at 4-percent and 7-percent discount rates.

Each present value entry in table 2 represents a sum of two calculations. The first is a discounting of all costs and returns occurring during the first rotation. The second is a discounting of all costs and returns from subsequent rotations. The second calculation is done to get around the problem of comparing dissimilar analytical time periods resulting from different rotation ages and ages at initial entry. For the second set of calculations, it was necessary to make assumptions about

Table 2--*The present value of selected management options, discounted to current stand age for five site classes. Present value is based on discounted (at 4 and 7 percent) values of the first rotation plus a perpetual series of rotations thereafter*

SITE I

Current stand age	Management alternative number	Proposed final harvest age	Total number of thinnings	Present value/acre at 7 percent		Present value/acre at 4 percent	
				Thinning regime	Stand unthinned	Thinning regime	Stand unthinned
Years		Years		Dollars			
30	1	30	0	NA[1/]	2,878	NA	4,181
	2	40	1	3,308	3,164	5,077	5,084
	3	50	2	2,998	2,428	5,214	4,883
	4	60	3	2,549	1,591	4,938	4,135
	5	70	4	2,173	962	4,498	3,273
	6	80	5	1,916	556	4,043	2,486
40	1	40	0	NA	6,223	NA	7,526
	2	50	1	5,215	4,777	7,372	7,228
	3	60	2	4,288	3,129	6,890	6,121
	4	70	3	3,572	1,893	6,246	4,844
	5	80	4	3,076	1,093	5,585	3,681
50	1	50	0	NA	9,396	NA	10,699
	2	60	1	6,850	6,155	9,321	9,060
	3	70	2	5,358	3,723	8,266	7,171
	4	80	3	4,379	2,151	7,272	5,448
60	1	60	0	NA	12,108	NA	13,411
	2	70	1	8,218	7,325	10,940	10,614
	3	80	2	6,232	4,229	9,390	8,065
70	1	70	0	NA	14,408	NA	15,711
	2	80	1	9,380	8,321	12,298	11,937

[1/] NA = not applicable.

SITE II

Current stand age	Management alternative number	Proposed final harvest age	Total number of thinnings	Present value/acre at 7 percent		Present value/acre at 4 percent	
				Thinning regime	Stand unthinned	Thinning regime	Stand unthinned
Years		Years		Dollars			
35	1	35	0	NA	2,567	NA	3,477
	2	45	1	2,723	2,591	4,041	4,058
	3	55	2	2,405	1,930	4,069	3,824
	4	65	3	2,032	1,251	3,820	3,215
	5	75	4	1,737	754	3,473	2,541
	6	85	5	1,536	435	3,124	1,933
45	1	45	0	NA	5,097	NA	6,007
	2	55	1	4,143	3,797	5,749	5,661
	3	65	2	3,389	2,459	5,330	4,759
	4	75	3	2,829	1,483	4,829	3,761
	5	85	4	2,449	857	4,328	2,862
55	1	55	0	NA	7,469	NA	8,379
	2	65	1	5,377	4,839	7,222	7,045
	3	75	2	4,205	2,917	6,387	5,568
	4	85	3	3,454	1,686	5,633	4,236
65	1	65	0	NA	9,518	NA	10,428
	2	75	1	6,427	5,740	8,471	8,242
	3	85	2	4,885	3,315	7,267	6,271
75	1	75	0	NA	11,290	NA	12,200
	2	85	1	7,334	6,523	9,544	9,283

Continued on p. 6

Table 2--*The present value of selected management options, discounted to current stand age for five site classes. Present value is based on discounted (at 4 and 7 percent) values of the first rotation plus a perpetual series of rotations thereafter*--Continued

SITE III

Current stand age	Management alternative number	Proposed final harvest age	Total number of thinnings	Present value/acre at 7 percent		Present value/acre at 4 percent	
				Thinning regime	Stand unthinned	Thinning regime	Stand unthinned
Years		Years		Dollars			
45	1	45	0	NA	2,726	NA	3,325
	2	55	1	2,430	2,272	3,422	3,425
	3	65	2	2,044	1,563	3,276	3,034
	4	75	2	1,650	974	2,963	2,473
	5	85	3	1,451	576	2,690	1,922
	6	95	4	1,297	330	2,407	1,449
55	1	55	0	NA	4,470	NA	5,069
	2	65	1	3,377	3,074	4,558	4,490
	3	75	2	2,697	1,918	4,113	3,661
	4	85	2	2,161	1,134	3,619	2,846
	5	95	3	1,925	648	3,260	2,145
65	1	65	0	NA	6,047	NA	6,646
	2	75	1	4,201	3,773	5,541	5,420
	3	85	2	3,240	2,231	4,820	4,213
	4	95	2	2,584	1,274	4,164	3,175
75	1	75	0	NA	7,423	NA	8,022
	2	85	1	4,914	4,388	6,391	6,236
	3	95	2	3,708	2,507	5,427	4,701
85	1	85	0	NA	8,631	NA	9,230
	2	95	1	5,541	4,931	7,138	6,958

SITE IV

Current stand age	Management alternative number	Proposed final harvest age	Total number of thinnings	Present value/acre at 7 percent		Present value/acre at 4 percent	
				Thinning regime	Stand unthinned	Thinning regime	Stand unthinned
Years		Years		Dollars			
60	1	60	0	NA	2,500	NA	2,841
	2	70	1	1,953	1,797	2,625	2,619
	3	80	1	1,521	1,153	2,371	2,191
	4	90	2	1,233	693	2,086	1,732
	5	100	2	1,053	401	1,852	1,321
	6	110	3	945	226	1,645	984
70	1	70	0	NA	3,536	NA	3,877
	2	80	1	2,507	2,267	3,287	3,243
	3	90	1	1,890	1,364	2,853	2,563
	4	100	2	1,526	788	2,462	1,956
	5	110	2	1,316	445	2,174	1,458
80	1	80	0	NA	4,460	NA	4,801
	2	90	1	2,993	2,682	3,870	3,794
	3	100	1	2,213	1,552	3,274	2,896
	4	110	2	1,775	874	2,787	2,157
90	1	90	0	NA	5,276	NA	5,617
	2	100	1	3,422	3,052	4,382	4,286
	3	110	1	2,498	1,721	3,644	3,194
100	1	100	0	NA	6,004	NA	6,345
	2	110	1	3,804	3,384	4,839	4,727

SITE V

Current stand age	Management alternative number	Proposed final harvest age	Total number of thinnings	Present value/acre at 7 percent		Present value/acre at 4 percent	
				Thinning regime	Stand unthinned	Thinning regime	Stand unthinned
Years		Years		Dollars			
90	1	90	0	NA	2,021	NA	2,172
	2	100	1	1,400	1,265	1,793	1,783
	3	110	1	1,057	752	1,541	1,397
100	1	100	0	NA	2,489	NA	2,640
	2	110	1	1,651	1,479	2,094	2,068

management practices that will follow the first rotation. It was assumed that timber would continue to be the main crop and that managers would seek a financially optimal rotation. Subsequent rotations were based on stand establishment, precommercial thinning costs, and returns from commercial thinning and final harvests.

Each present value entry is discounted to current stand age (shown in the first column of table 2). For example, for site I all present values in the first six lines (management alternatives 1 to 6) are discounted to age 30.

The financial assumptions behind the data shown in table 2 follow:

1. Timber volumes harvested were valued by using a net stumpage value of $138 per thousand board feet Scribner for final harvest timber (based on the average stumpage price for Douglas-fir sawtimber sold on National Forests in the Douglas-fir region in 1973) and $103.50 per thousand board feet for thinning stumpage (assumed to be 75 percent of final harvest stumpage). There was no adjustment of stumpage price based on diameter.

2. Rotations subsequent to the first rotation were financially optimized and based on the prices shown above plus costs of $75/acre for regeneration and $70/acre for precommercial thinning.

3. Net stumpage values were assumed constant over time. There was no attempt to estimate future rates of inflation nor future rates of increase in the value of wood products relative to other products. Since current interest rates reflect inflationary trends, an analysis that uses constant prices also needs adjustment of the discount rate for inflation. Just what the appropriate rate should be depends on the time, the circumstance, and the investor. The rates of 4 percent and 7 percent are offered here both to contrast the effects of different rates and as reasonably close approximations of what noninflationary, before-tax rates may be.

4. The financial returns shown in table 2 do not include administrative costs nor do they account for taxes.

Financial Guidelines

Table 2 can be used in at least two ways that might aid decisionmaking. On the one hand, when financial returns are paramount, it can be used to determine rotation length and to decide whether to thin or not. On the other hand, if rotation length is already established (probably for reasons other than financial), the table can be used to find out what would be gained from commercial thinning as opposed to not thinning.

To use table 2 in the financial case, one must specify current stand age, site class, and interest rate. With this information, one is given a set of numbered management alternatives representing "proposed final harvest ages." The financial solution is the highest number under the columns "thinning regime" and "stand unthinned." For example, if current stand age is 30, on site class I at 4 percent, the solution is the value $5,214, indicating that the stand would be thinned twice and grown to age 50 when it would be harvested. If current stand age is 40, on site class I at 4 percent, the financial solution is $7,526, indicating that the stand should be harvested immediately.

To further illustrate finding the financial solution, assume that a 35-year-old site II Douglas-fir stand has a 4 percent real rate of interest adjusted for inflation. To find the optimal decision, look for the highest number under the 4-percent heading in the block of numbers representing site II at current stand age 35. That number is $4,069, indicating that the

stand can be held to age 55 and thinned twice, now and at age 45.

To illustrate a situation where rotation age is set, assume that the 35-year-old site II stand discussed above has a specified rotation of 75 years. At 4 percent, the thinning regime is worth $3,473 while the non-thinning regime is worth $2,541, a net difference of $932 per acre in favor of thinning. Note, however, that the highest financial solution is worth $4,069.

The thinning regimes assumed for table 2 begin immediately if the decision is made to thin and thinning is done frequently. What are the results if thinning is delayed or done less frequently? In the case of the 35-year-old site II stand, the financial consequences of delaying the first thinning to age 45 and still harvesting at age 55 at 4 percent can be found in table 2. With a current stand age of 45 and a final harvest age 55, the value of an initial entry at age 45 (discounted to age 45) is $5,749. The next step is to discount this figure 10 years to age 35 and then compare alternatives. The present value of delayed thinning is $3,884. This represents a loss compared to the regime with two thinnings.

Only a few runs were made to test what happens with less frequent thinnings. On the basis of limited data, it appears that present net values are reduced somewhat if there is any reduction in thinning frequency.

In general, the financial solutions shown in table 2 will hold for reasonable changes in the assumptions concerning stumpage price levels and price-diameter relationships. Stumpage price levels reflecting the range of price levels over the last 10 years were tested with no appreciable change in the optimal rotations or relationship of thinning to no thinning. Likewise, there was no appreciable change in the results when stumpage price as a function of diameter was changed so that prices ranged from a low of $113 for 9-inch (22.9-cm) trees to $138 for 21-inch (53.3-cm) trees; thinning values were assumed to be 75 percent of these.

The most dramatic changes occurred with discount rates outside the 4- to 10-percent range. For rates above 10 percent, liquidation as soon as the stand reached merchantable size was indicated. Below 4 percent, financially optimal rotations tended to increase about 10 years for every drop of 1 percent. For higher sites (I to III), this increased thinning opportunities by increasing the age at which thinning was financially feasible. On lower sites, however, leaving the stand unthinned was generally the financially optimal solution.

Conclusions

The value of commercial thinning in previously unthinned merchantable stands of Douglas-fir depends primarily on the goals of management. If optimization of financial returns is the primary goal, managers interested in commercial thinning should direct their attention to higher sites and young stands that have recently reached merchantable size. Older stands and stands on lower sites would be harvested and a new crop started. If financial goals are subordinated to other goals, then rotations will probably be longer than those set by financial criteria. In such cases, thinning will, in general, be financially preferable to leaving the stand unthinned. In addition, longer rotations also provide increased opportunities to increase volume production.

GPO 998-336

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-294 March 1977

MORPHOLOGY OF THE INTERNAL REPRODUCTIVE ORGANS IN RELATION TO THE SEX PHEROMONE GLANDS OF THE SPEAR-MARKED BLACK MOTH

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by

Richard A. Werner, *Research Entomologist*

ABSTRACT

The morphology of the male and female internal reproductive organs of *Rheumaptera hastata* (L.) is described and illustrated. A new type of sex pheromone-producing gland was found in adult females. Unlike those of other Lepidoptera whose glands are modified intersegmental membranes, the paired glands of this geometrid moth are internal in structure and function. The opening of the common duct from the paired glands is in the posterior region of the vagina, and the sex pheromone is released by pulsation of the terminal abdominal segments.

KEYWORDS: *Rheumaptera hastata*, reproductive organs (insect), morphology, attractants.

Introduction

The morphology of the internal reproductive system of the spear-marked black moth, *Rheumaptera hastata* (L.), has not been previously reported, though McGuffin (1973) described the external genitalia. The information presented in this paper resulted from a study on the role of sex pheromones in mating behavior of *R. hastata* (Werner 1977). Sex pheromone glands were found in the terminal abdominal segments of female moths and this prompted an investigation on the morphology of the reproductive organs in order to positively describe the location of the glands.

Materials and Methods

Unmated adults of *R. hastata* were reared from field-collected pupae. Moths were anesthetized with carbon dioxide, wings and legs excised, and abdominal scales removed with adhesive tape (Fatzinger 1970). The insect was then dissected in Bouin's fluid and the exposed reproductive organs stained with fast green. Measurements were made on 10 moths of each sex using an ocular micrometer.

Results and Discussion

The male reproductive system of *R. hastata* (fig. 1) is basically similar to that of other Lepidoptera in that the testes (T) are paired and enclosed in a single large spherical scrotum about 1.45 mm in diameter. The reddish-brown, thin-membranous scrotum is located dorsally between the third and fourth abdominal segments. The testes of newly emerged adults were filled with live sperm which suggests that male moths are sexually mature when they emerge from the pupa.

Paired vasa deferentia (VD), about 5-7 mm in length, arise from the ventral side of the testes and extend to the ductus ejaculatorius duplex (DED). Two seminal vesicles (SV) appear in each vas deferens about 1 mm distal from the testes. A second pair of seminal vesicles known as the accessory seminal vesicles (ASV) are located at the junction of the vasa deferentia and ductus ejaculatorius duplex. Live sperm were also found in the seminal vesicles which serve as a storage area for sperm.

The ductus ejaculatorius duplex is located dorsally, and the paired organs are fused posteriorly to form the single ductus ejaculatorius simplex (DES). Each duplex is about 3 mm long and 0.5 mm in diameter. At the anterior end, each duplex narrows to form an accessory gland (AG). The vas deferens enters each duplex near the anterior end. The accessory glands are 7.5 to 8.0 mm long and were found to contain a white substance. These glands, which secrete the seminal fluid, appear united but are merely connected by tracheal tissue. The ductus ejaculatorius simplex is about 22-25 mm long and in *R. hastata* consists of two distinct segments: the anterior primary segment (PS) and the posterior cuticular segment (CS). According to Callahan (1958), the simplex of *Heliothis zea*, is composed of two morphological areas as was found in *R. hastata*. But Outram (1970) describes seven morphological divisions in *Choristoneura fumiferana;* whereas, Norris (1932) found four divisions in *Ephestia kühniella* and Khalifa (1950) reported six divisions in *Galleria mellonella*. Fatzinger (1970) also reports two morphological divisions in *Dioryctria abietella*. The cuticular segment is differentiated into the ejaculatory bulb (EB) which functions in forming the spermatophore in most Lepidoptera including *R. hastata*. Spermatophore precursor substances were found in the primary segment of unmated males. The posterior end of the ductus ejaculatorius simplex terminates in the aedeagus (AE). McGuffin (1973) described the aedeagus as a stout structure containing three cornuti with the possibility that the cornuti are deciduous.

The female reproductive system (fig. 2) is similar to other ditrysian Lepidoptera in that the bursa copulatrix (BC) is connected to the common oviduct (OVC) by a seminal duct (DS). The ostium bursae (OB) opens externally midventral in the intersegmental cuticula of the seventh and eighth sternite and the ovipore (OP) and rectum (RE) on the ninth sternite.

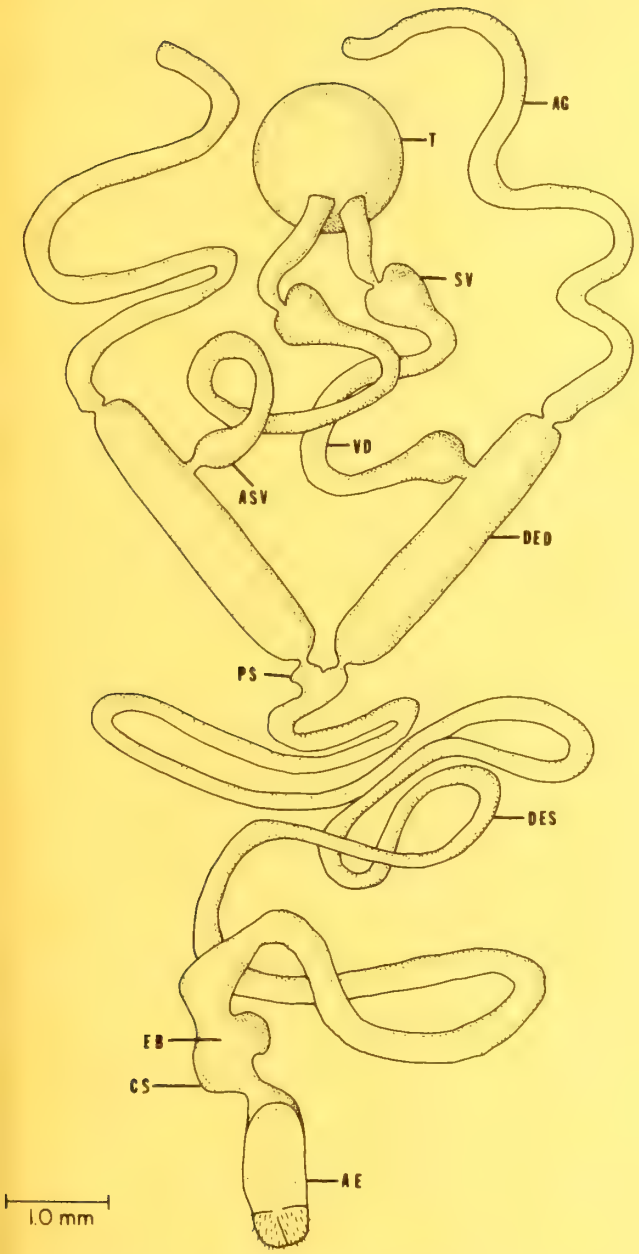

Figure 1.--Reproductive organs of male R. hastata. AE, aedeagus; AG, accessory gland; EB, ejaculatory bulb; CS, cuticular segment of ductus ejaculatorius simplex; DED, ductus ejaculatorius duplex; DES, ductus ejaculatorius simplex; SV, seminal vesicle; T, testis; VD, vas deferens; ASV, accessory seminal vesicles; PS, primary segment.

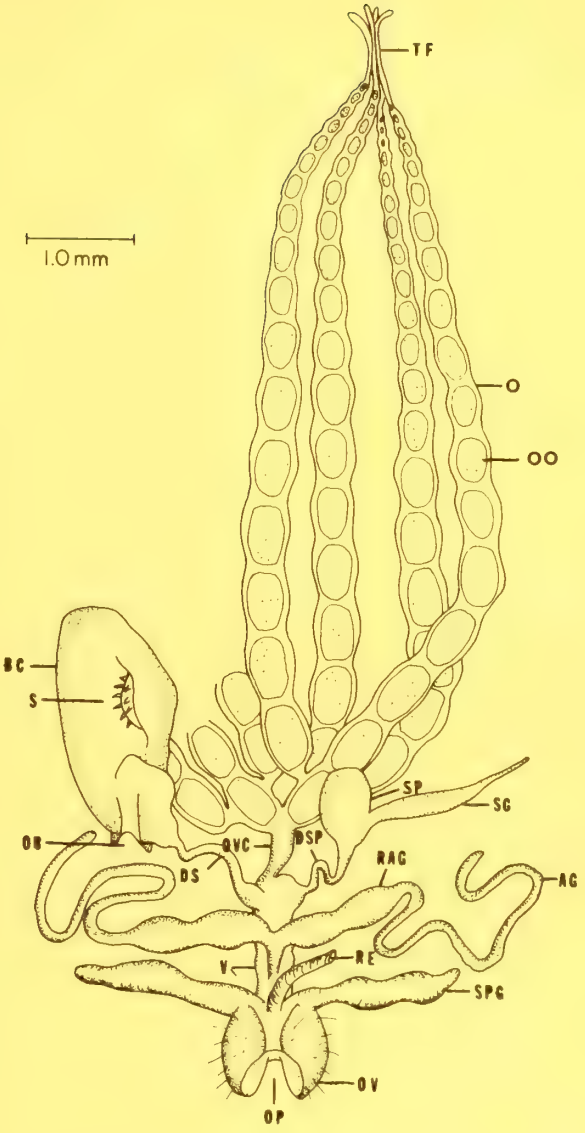

Figure 2.--Reproductive organs of female R. hastata. AG, accessory gland; BC, bursa copulatrix; DS, seminal duct; DSP, spermatheca duct; O, ovariole; OB, ostium bursae; OO, oöcyte; OP, ovipore; OV, ovipositor; OVC, common oviduct; RAG, reservoir of accessory gland; RE, rectum; SG, spermathecal gland; S, signum; SP, spermatheca; SPG, sex pheromone gland; TF, terminal filament; V, vagina. Ovarioles of left ovary are not shown.

The system contains paired ovaries, each ovary consisting of 4 polytrophic ovarioles (O) and each arising from a separate terminal filament (TF). The ovarioles of newly emerged, unmated females are longer (8-9 mm long) than the abdomen but are folded and extend from the seventh to the second abdominal segment.

Each ovariole of newly emerged females contains from 15 to 25 oöcytes (OO), with the mature oöcytes located at the proximal end where the ovarioles are connected by the short lateral oviducts to the common oviduct. The latter (2-3 mm long) is connected at the anterior end to the lateral oviducts and has two ducts leading into it before it terminates posteriorly in the vagina (V).

The first of the four ducts is the seminal duct (DS) which connects the bursa copulatrix to the common oviduct. The seminal duct is 1.0-1.5 mm long and opens into the common oviduct immediately posterior to the junction of the lateral oviducts.

The bursa copulatrix of *R. hastata* is a large brownish, muscular organ which was found to contain a spermatophore in mated females. In unmated females, the bursa copulatrix appears smaller and flattened. A heavily sclerotized signum (S) is located in the center of the bursa. The signun is somewhat oblong, 0.5 mm long, rigid with sharp spines.

The spermatophore is inserted through the sclerotized ostium bursae (OB), which is an external opening located midventrally in the intersegmental cuticula of the seventh and eighth abdominal sternites. The morphology of the spermatophore will not be described in this paper.

The spermathecal duct (DSP) (1.0-1.5 mm long) connects the spermatheca (SP) and spermathecal gland (SG) to the common oviduct opposite the seminal duct. Live sperm were found in the seminal duct, spermathecal duct, and spermatheca of mated females which indicates the latter functions to store sperm. Callahan and Cascio (1963) first described the movement of sperm from the spermatophore in the bursa copulatrix, through the seminal duct, across the common oviduct, and up the spermathecal duct to the spermatheca.

Posterior to the opening of the spermathecal duct, the common oviduct opens into the vagina. A pair of accessory gland reservoirs (RAG) (1.5-1.8 mm long) are situated posterior to the spermatheca and bursa copulatrix and connect by a common duct to the dorsum of the anterior region of the vagina. Each accessory gland reservoir constricts anteriorly into an accessory gland (AG) (4.0-5.0 mm long). A pinkish secretion was found in the accessory gland reservoirs.

R. hastata females have an additional pair of internal glands which open via a common duct into the dorsum of the posterior region of the vagina. These are the sex pheromone glands (SPG) and were found through bioassay to produce the female sex pheromone during courtship behavior. Previous reports indicate that all sex pheromone glands have external openings somewhere on the terminal region of the abdomen (Urbahn 1913, Götz 1951, Jefferson et al. 1968, Percy and Weatherston 1971). The sex pheromone glands of *R. hastata* open in the vagina, and the sex pheromone is released by a pulsating action of the terminal abdominal segments. Urbahn (1913) described similar internal glands in several species of Arctiidae and an external opening between the eighth and ninth abdominal tergite.

Posterior to the sex pheromone gland, the vagina opens into a telescopic ovipositor (OV), which has an ovipore for egg laying and for the dispersal of sex pheromone and accessory gland secretions. The ovipore is located on the fused ninth and tenth abdominal segment ventral to the anus.

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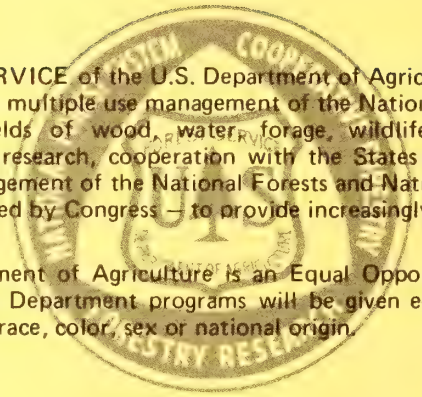

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USDA FOREST SERVICE RESEARCH NOTE

PNW-295 April 1977

DOUGLAS-FIR TUSSOCK MOTH EGG HATCH AND LARVAL DEVELOPMENT IN RELATION TO PHENOLOGY OF WHITE FIR IN SOUTHERN OREGON [1/]

Boyd E. Wickman, *Principal Insect Ecologist*

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Abstract

Bud burst, shoot elongation, egg hatch, and larval development were studied on two areas near Fort Klamath, Oregon. The study areas had low population levels of the Douglas-fir tussock moth. Bud burst was found to be closely related to accumulated degree-days, and peak egg hatch occurred after all buds had burst and shoots were 40 percent elongated. Larval development then closely followed shoot elongation. The findings are similar to those from earlier studies in California and northeastern Oregon.

KEYWORDS: *Insect populations, larval growth, reproductive behavior (insect), bud burst, shoot growth, phenology, white fir, Douglas-fir tussock moth,* Orgyia pseudotsugata, *Oregon (southern).*

INTRODUCTION

The phenology of Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), and its hosts has been studied and reported in California (Wickman 1976b) and northeastern Oregon (Wickman 1976a). In both studies the synchrony of insect and host phenology was noted, particularly egg hatch following bud burst. This synchrony between insect and host means that new foliage, which is obligatory food for early instar larvae, is available immediately after egg hatch.

[1/] Research leading to this publication was financed in whole or part by the USDA Expanded Douglas-fir Tussock Moth Research and Development Program.

Studies of tussock moth population ecology in the Fort Klamath, Oregon, area in 1976 offered an opportunity to determine the phenology of insect and host in an additional area to see if the synchronous relationships were similar to those observed in previous studies. This area was particularly valuable since it is one of the few known white fir (*Abies concolor*) (Gordon and Glendenning) Lindley) stands in the West with a static low-level tussock moth population. Also, the stand is located approximately midway between the sites of earlier phenology studies in the Central Sierra Nevada of California and the Blue Mountains of northeast Oregon.

This study also provided phenology and degree-day information for concurrent population studies which facilitated sampling and scheduling of other research activities.

METHODS

The methods were similar to those used by Wickman (1976a) in the northeastern Oregon study.

LOCATIONS OF STUDY AREAS

In April 1976, two study sites were located in an area with a low-level tussock moth infestation near Mare's Egg Spring, (10 km) southwest of Fort Klamath, Oregon. Each site was also the location of a population study plot. Two elevations were sampled:

Population plot C--4,500-foot (1 350-m) elevation, eastern exposure, open-grown mixed white fir, ponderosa pine (*Pinus ponderosa* Laws.); second growth, thinned stand.

Population plot H--4,200-foot (1 250-m) elevation, eastern exposure, open-grown mixed white fir, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), ponderosa pine; old-growth stand.

At each plot eight open-grown white fir trees, 8 to 15 feet (2.4-5 m) in height, were marked. There were some Douglas-fir on plot H, but small sample size trees were difficult to locate so only one Douglas-fir was tagged and measured.

TEMPERATURE RECORDS

Air temperature recording station, consisting of 31-day recording hygrothermographs and a maximum-minimum thermometer in a standard weather shelter, were located on each plot.

A threshold temperature of 42 °F (7 °C) was used so that the study was comparable with previous tussock moth phenology studies (Wickman 1976a, 1976b). The sum of daily average temperatures above 42 °F was used for accumulated heat units. Accumulated degree-days for each plot were calculated from these heat units.

FOLIAGE SAMPLING

Each study tree had four tagged primary branches on the four cardinal sides of the midcrown. In April one terminal bud on each branch was marked, measured, and examined and then remeasured at 3- to 6-day intervals from May 19 through the period of bud development, egg hatch, and dispersal of new larvae from the egg masses. Additional measurements were made at midseason (July 8) and after shoot growth ended (August 10 and September 8).

For this study, bud burst is defined as the time when individual needles first begin to protrude from the transparent sheath encasing

expanding buds and are available to the young larvae for feeding.

EGG MASS EXAMINATIONS AND LARVAL SAMPLES

In late March, laboratory-reared egg masses were wired on four mid-crown branches on two sample trees per plot. By late April, 12 of the 16 egg masses had been partially or totally destroyed, probably by birds. The design was then changed to monitor field collected egg masses used for the population studies.

In mid-June, 10 egg masses were wired on 10 white fir branches on a population study plot at the same elevation (4,200-foot, 1 250-m) and 0.5 mile (0.8 km) south of plot H. These egg masses were examined once or twice a day through the period of egg hatch and dispersal. Peak hatch was defined as an egg mass almost completely covered by new larvae.

Using a standard sampling technique, Mason (1977) sampled feeding larvae from the lower crown foliage of 100 nearby trees on each plot every 3 weeks until pupation. The predominant larval instar at a given sample date was then compared with average shoot growth.

RESULTS AND DISCUSSION

Field measurements involved several steps which demonstrated a relationship between the phenology of the tussock moth and white fir, its principal host at Fort Klamath. Degree-days were accumulated by date and compared between the two plots to point out elevational differences; then degree-days were compared with bud burst at each site. Egg hatch was monitored and related to degree-days and bud burst; and, finally, shoot elongation was compared with egg hatch, larval dispersal, and larval development. The results for these comparisons follow.

DEGREE-DAYS AND BUD BURST

Degree-day accumulation was related to elevation with the lower plot (H) several days ahead of the higher plot (C) (fig. 1). Figure 2 shows bud burst by degree-days for white fir on each plot and reveals a fairly consistent pattern of development. Bud burst monitored on the single Douglas-fir at plot H is not graphed, but it consistently lagged several days behind bud burst of white fir on the plot. This was also true of other Douglas-fir observed in the area. In northeastern Oregon in 1973 Douglas-fir buds burst several days after grand fir at higher elevations also; but at low elevations (3,200 feet, 975 m) the reverse was true (Wickman 1976a).

The bud burst data in figure 3 indicate that the elevational differences of 300 feet (100 m) between plots was sufficient to reflect developmental delay of bud burst as proposed by Hopkin's Law (1918).

Bud burst often occurred first on open-grown trees, but as bud burst progressed there was no substantial difference by aspect in the crown. This agrees with findings in northeastern Oregon and California (Wickman 1976a, 1976b).

Bud burst as plotted in figure 2 started between 313 and 347 degree-days and proceeded rapidly until 90 percent of the bud burst had occurred between 500 and 510 degree-days. These values, shown in table 1, are higher than those found in northeastern Oregon but close to those found in California (Wickman 1976a, 1976b). The reasons for the differences in Oregon might be related to difference in spring weather between

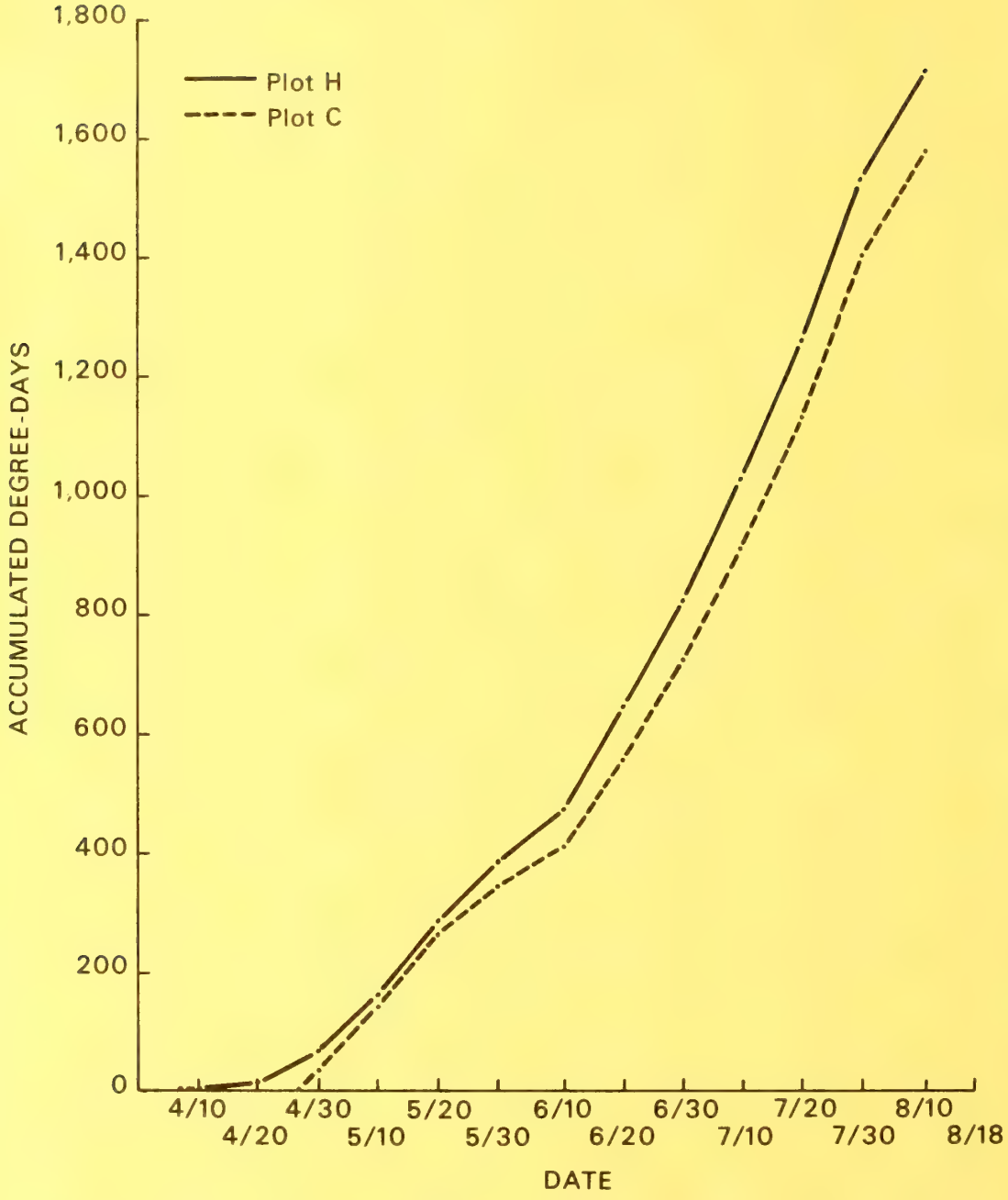

Figure 1.--Accumulated degree-days, April-August 1976, on phenology plots, Mare's Egg Spring, Oregon.

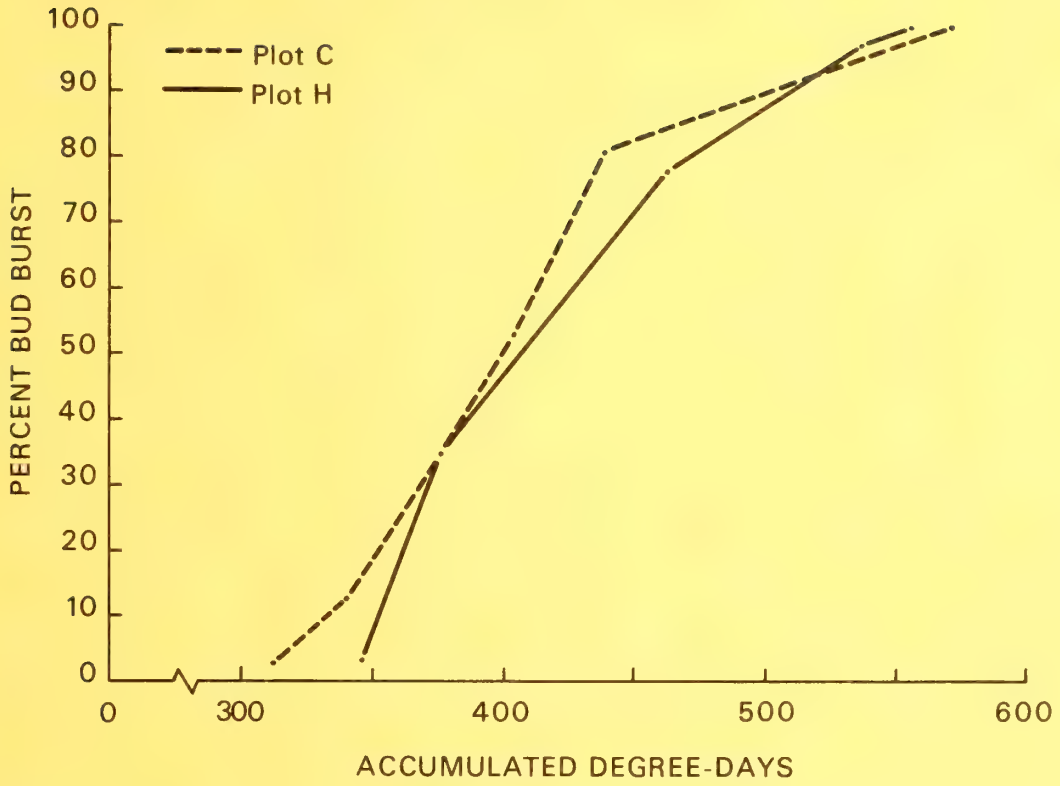

Figure 2.--Accumulated degree-days and percent bud burst, May-June 1976, on phenology plots, Mare's Egg Spring, Oregon.

localities and years. The same host is involved in both areas so, probably, southern Oregon phenological events are more similar to those in central California.

DEGREE-DAYS, BUD BURST, AND EGG HATCH

The relationship of egg hatch on the nearby population study plot to accumulated degree-days at plot H is shown in table 2. The sample is small (10 egg masses) because of scarcity of naturally deposited egg masses and their use for population studies. Also, the egg masses were monitored 0.5 mile (0.8 km) from plot H, but at the same elevation and in a similar stand. Egg hatch and dispersal from these 10 egg masses took place in 7 days with a degree-day accumulation of 625 at first hatch and 725.5 at peak hatch and dispersal. The data were not quantified the same way as for previous studies because of a shortage of egg masses, but, in this study, the time frame for egg hatch and dispersal is shorter than the 7-14 days in northeastern Oregon or the 13-17 days in California (Wickman 1976a, 1976b).

The egg hatch data are also suspect because egg masses were wired on exposed branches with a muslin drop cloth permanently fastened about 20 inches (50 cm) under each egg mass. This arrangement probably resulted in more

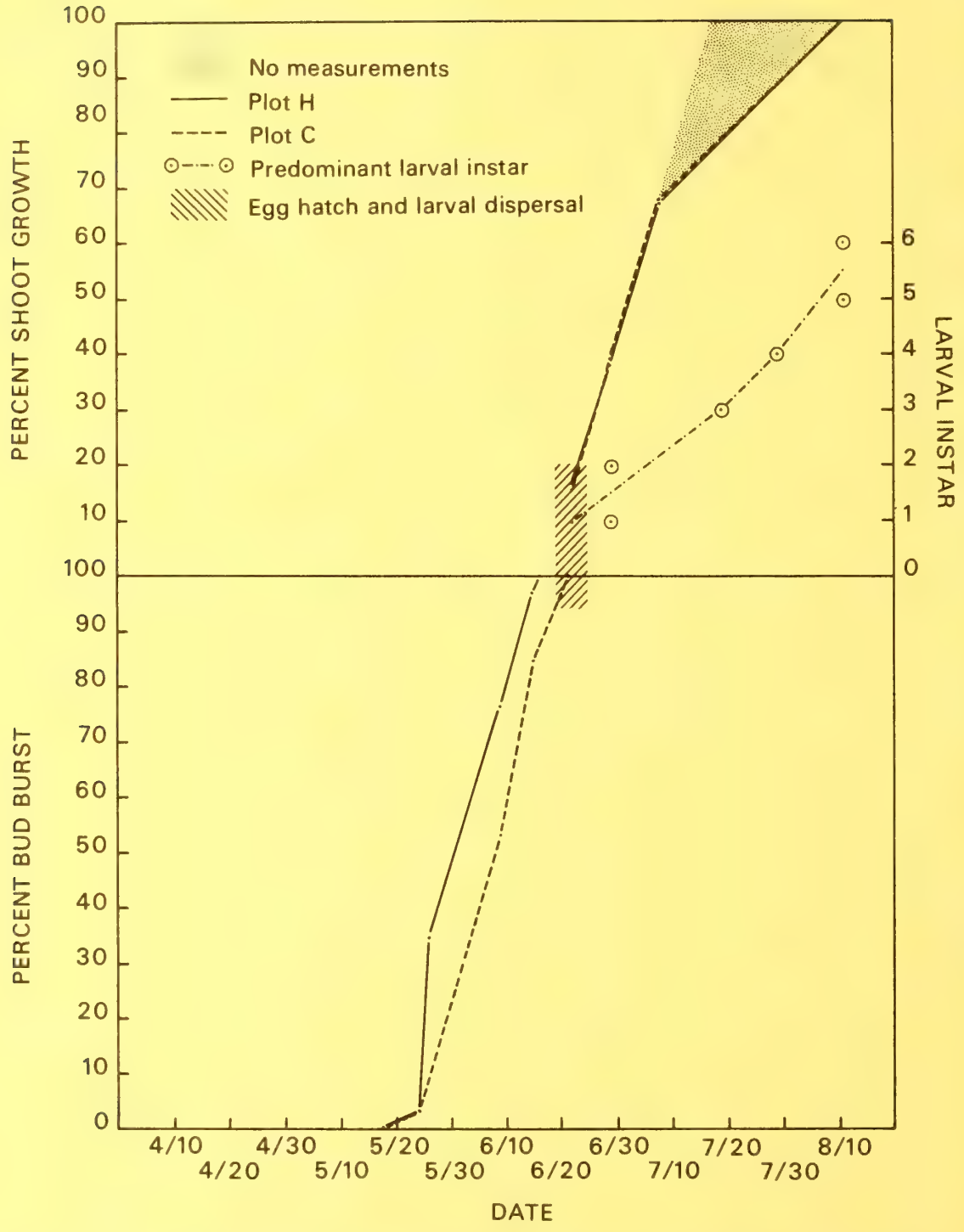

Figure 3.--Percent bud burst and shoot growth by date related to egg hatch, larval dispersal, and larval development for plots C and H, Mare's Egg Spring, Oregon, 1976.

Table 1--*Accumulated degree-days related to bud burst at 3 locations*

Location	First bud burst	90 percent bud burst
	Degree-days	
Central California	290-356	464-535
Southern Oregon (Fort Klamath)	313-347	500-512
Northeastern Oregon	244-268	340-386

Table 2--*Egg hatch and dispersal from 10 egg masses collected on the plot site and attached to branches for population studies, Fort Klamath, Oregon, 1976*

Date	Degree-days	Unhatched	Hatch underway	Peak hatch and dispersal
		Number		
6/19	625	9	1	0
6/22	674.5	2	3	5
6/23	692	2	--	8
6/24	711	0	2	8
6/25	725.5	0	0	10

exposure to solar radiation than that received by egg masses used in previous studies. The increased solar radiation may have resulted in a shorter period for egg hatch.

Calendar date plotted against percent bud burst and egg hatch is illustrated by figure 3. Figure 3 indicates that first egg hatch occurred after 100 percent bud burst on plot H. We had no equivalent measurements for plot C. Table 3 compares the two earlier studies (Wickman 1976a, 1976b) with this study. Because of the small egg sample in this study, comparisons of egg hatch with the other areas are tenuous, but other values are similar for the three areas which indicates synchrony of bud burst with egg hatch. Most important, by the time all larvae had dispersed from the egg masses to new foliage and were feeding, all buds had burst and shoots were over 40 percent elongated. This value is intermediate to shoot elongation in California (10-20 percent) at complete dispersal from egg masses and in northeastern Oregon (85-90 percent).

Table 3--*First egg hatch related to percent bud burst at 3 locations*

Location	Host	Percent bud burst (at first egg hatch)
Central California	White fir	63-86
Southern Oregon	White fir	100
Northeastern Oregon	Grand fir	86-100
Northeastern Oregon	Douglas-fir	70-97

SHOOT ELONGATION AND LARVAL DEVELOPMENT

Average shoot length and cumulative percent growth by date and degree-days are shown in table 4. The time that shoot growth was completed is not known because of a long period in late summer when no measurements were taken (shaded portion at top of fig. 3). The configuration of shoot growth curves in the northeastern Oregon and California studies (Wickman 1976a, 1976b) indicate that growth was completed sometime between July 15 and August 11, most likely the last week of July.

The trend is similar to the California and northeastern Oregon studies, with rapid shoot elongation accompanying larval development. By the third and fourth instars, between 80 and 90 percent of the shoot growth had taken place; this assured an adequate food supply for the rapidly growing larvae. Food supply was more than adequate for this particular population. But in northeastern Oregon in 1973 food supply was critical for the extremely large populations, and shoot growth was 90 percent complete by the second instar (Wickman 1976a). In California, where populations were sparse, 50 percent of the shoot growth had

Table 4--*Average shoot growth and degree days, Mare's Egg Spring, Oregon, plots C and H, 1976*

Date	Plot C			Plot H		
	Degree-days	Average shoot length	Accumulated growth	Degree days	Average shoot length	Accumulate growth
		Inches (cm)	Percent		Inches (cm)	Percent
6/22	584	0.97 (2.46)	15.2	674	1.36 (3.45)	16.7
6/29	714	1.51 (3.84)	38.9	811	1.72 (4.37)	37.8
7/8	871	1.83 (4.65)	67.7	983	2.39 (6.07)	67.1
8/10	1,579	2.6 (6.52	100.0	1,712	2.68 (6.81)	100.0

taken place during the third and fourth larval instars (Wickman 1976b). Again, Fort Klamath was intermediate between California and northeastern Oregon.

As in the other studies, aspect caused no appreciable difference in shoot growth, either by development rate or total length.

CONCLUSIONS

This study indicated similar phenological relationships for tussock moth egg hatch and larval development on white fir in southern Oregon, white fir in central California, and grand fir and Douglas-fir in northeastern Oregon. The study area near Fort Klamath had almost the same relationship of degree-days and bud burst as the California study site and almost the same relationship of percent bud burst at egg hatch as the northeastern Oregon study site; it was intermediate between the California and northeastern Oregon areas for shoot elongation and larval development relationships. None of the differences seemed great, but limited sample sizes, and the artifact of each study carried out in a different year prevented tests for significance.

The important finding was that the relationships seem so consistent between areas and years. Some variation is bound to occur because of differences in tussock moth populations, host species, stands, physiography, and climatological seasons, but for the three studies the phenological synchrony between insect and host seems consistent.

This consistency also underscores the use of bud burst and shoot elongation as field predictors of egg hatch and larval dispersal rather than monitoring of individual egg masses.

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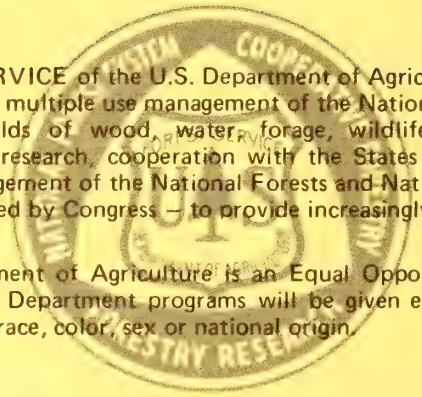

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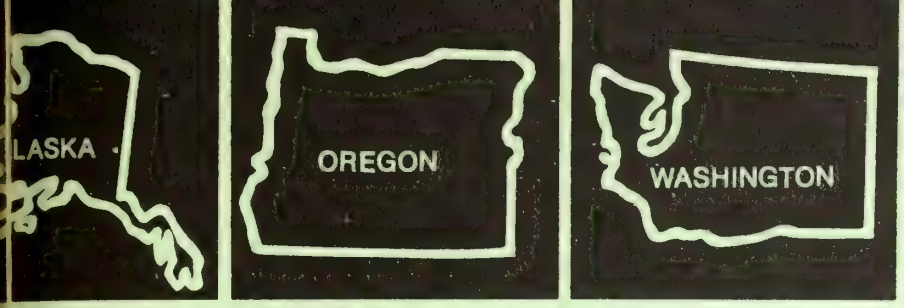

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-296

April 1977

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ARSENIC IN CATTLE HAIR AFTER FORESTS ARE PRECOMMERCIALLY THINNED WITH ORGANIC ARSENICAL HERBICIDES

by

Logan A. Norris, *Supervisory Research Chemist*

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ABSTRACT

Arsenic levels were measured in hair taken from cattle grazed in northeast Washington forests. The forests were precommercially thinned with MSMA or cacodylic acid. Cattle from two of three study areas showed an increase in arsenic levels during the grazing season. In an untreated area, arsenic levels in cattle also increased during the grazing season. In all cases the levels of arsenic were within the normal range which indicates that herbicides were handled and applied with sufficient care to prevent appreciable exposure of cattle.

KEYWORDS: Herbicide side effects, cattle, thinning (precommercial), arsenic, cacodylic acid, MSMA.

INTRODUCTION

MSMA (monosodium methanearsonate) and cacodylic acid (dimethylarsinic acid) are effective chemical agents in precommercial thinning of overstocked stands of conifers in northeastern Washington. In these treatments, undiluted herbicide concentrate is injected into axe cuts which are spaced approximately 7 cm around the stem of the tree about 1.5 m above the ground.

Cattle may be grazed for at least part of the year in chemically thinned stands. It is possible, therefore, that cattle could be exposed to arsenic (As) either through careless handling and application of the herbicide or through the movement of chemical residues from treated trees to nearby vegetation which is then eaten by these animals.

Arsenic is commonly accumulated in the hair of mammals. Human hair contains As at concentrations between 0.03 and 1 ppm (Smith 1967, Vallee et al. 1960, Rothman 1954). Exon et al. (1974) reported a threefold increase in As in the hair of rabbits exposed to MSMA in their diet for 12 weeks. The concentration of As in cattle hair nearly doubled during a 10-day exposure to MSMA, and increased 35 times during a 48-day exposure to cacodylic acid (Dickinson; 1972, 1975). On this basis I believe arsenic in hair should be a reasonable index of the degree of exposure cattle receive when they are grazing in forested areas which have been precommercially thinned with the organic arsenical herbicides.

In 1969, the Okanogan National Forest reported the death of eight range cattle in forest areas treated with these herbicides. Arsenic levels were slightly elevated in several body tissue specimens taken from these animals, but were not of diagnostic significance. As a result of this incident and because of concern about applicator exposure, a cooperative study of the behavior and impact of organic arsenical herbicides in the forest was initiated by the Pacific Northwest Forest and Range Experiment Station and Region 6 of the Forest Service.

The study included several State and Federal agencies, universities, companies, and private individuals. As part of the cooperative arsenic study, Dr. Hugh Maycumber, DVM, a private veterinarian in Tonasket, Washington, measured arsenic in hair from cattle grazed in thinned areas. Maycumber's findings are given in the final report of the cooperative arsenic study, but his report has not been widely distributed.[1/] I have included a brief description of his study and his results for easy comparison with the findings of my study.

[1/] Norris, Logan A. 1974. The Behavior and Impact of Organic Arsenical Herbicides in the Forest: Final Report on Cooperative Studies. 98 pages on file. Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon.

Maycumber found a statistically significant increase, between spring and fall, in the concentration of arsenic in the hair of cattle grazed in treated areas. A shortage of holding facilities, however, prevented him from sampling hair from cattle grazing in untreated areas. As a result, it was not possible to tell if the increase he detected was caused by exposure to arsenic from thinning operations or from the accrual of arsenic naturally present in the environment. I attempted to resolve this point by repeating a portion of Maycumber's study but included hair samples from cattle which had grazed in untreated areas.

METHODS

THE MAYCUMBER STUDY

The Mt. Hull study area on the Okanogan National Forest was thinned in 1969 with Glowon® (MSMA) Tree Killer and Silvisar 510® (cacodylic acid) and was the site of cattle deaths the same summer. Hair samples were collected from 37 head of cattle on June 26, 1970, before the animals were turned out to graze for the summer and approximately 1 year after the grazing area had been thinned. A second collection of hair from the same animals was made on October 14, 1970.

The Mill Creek study area is on the Colville National Forest. It was thinned with Silvisar 550® (MSMA) during the summer of 1970. Hair samples were taken from 28 cattle on May 29, 1970, before they were turned out to graze, and a second hair collection was made on September 9, 1970. The cattle were in the Mill Creek study area during the chemical thinning operation. At the end of the grazing period, tissues from two of these cattle were analyzed for arsenic residues. A female deer, recognized as a regular inhabitant of the Mill Creek area during the 1970 thinning season, was also killed. Various tissues from the deer were analyzed for arsenic residues.

THE NORRIS STUDY

This study was done in a mixed western larch (*Larix occidentallis* Nutt.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forest in the *Pseudotsuga menziesii* Zone near Colville, Washington (Franklin and Dyrness 1973). Approximately 290 ha of a 365-ha grazing allotment were thinned with MSMA between 1969 and 1974. On June 13, 1973, 12 cattle, selected at random, were marked and hair samples were collected for arsenic analysis. These animals grazed throughout the area from June 18 to October 12. On October 16, 1973, hair samples were collected from the same animals. Approximately 75 ha of the allotment were thinned with MSMA during the time the cattle were in the area. In a similar, nearby area which had not been previously thinned chemically, hair from 12 marked animals, selected at random, was also collected in June and again in October.

Arsenic in hair from the Maycumber study was analyzed by neutron activation at Washington State University, Pullman (Thomas and Kristensen 1968). Hair samples from the Norris study and

tissue samples from the Maycumber study were oxidized by digestion with nitric-sulfuric acid to remove organic matter. The arsenates were reduced to arsine which was trapped in silver diethyldithiocarbamate in pyridine forming a colored complex which was spectrophotometrically measured. Analyses were done by the Washington Department of Social and Health Services at Wenatchee.

RESULTS

MAYCUMBER STUDY

Levels of arsenic from the hair of cattle grazed on the Mt. Hull and the Mill Creek study areas are shown in table 1. I tested Maycumber's data with a paired t-test which showed that the increase in arsenic concentration between spring and fall samples was statistically significant ($P<0.05$) at both sites. A t-test showed no significant difference ($P>0.05$) between the two sites for samples collected at the same time. The lack of samples from animals grazed in untreated areas prevents a determination of whether or not the increase in arsenic concentration in hair during the summer grazing season was a result of the chemical thinning program.

Table 1--*Arsenic in hair from cattle grazed in forest areas thinned with MSMA or cacodylic acid, Maycumber's study*

Mt. Hull Study Area[1]			Mill Creek Study Area[2]		
Animal number	Spring 1970	Fall 1970	Animal number	Spring 1970	Fall 1970
	-- ppm[3] --			-- ppm[3] --	
1	0.56	0.33	1	0.18	0.44
2	0.39	0.65	2	0.20	0.27
3	0.47	0.74	3	0.24	0.61
4	0.96	1.20	4	0.23	0.30
5	0.18	0.56	5	0.48	0.98
6	1.28	0.81	6	0.25	0.45
7	1.04	1.53	7	0.64	0.59
8	0.27	1.14	8	0.39	0.94
9	0.73	1.07	9	0.21	0.90
10	0.41	1.28	10	0.24	0.35
11	0.35	0.77	11	0.58	1.02
12	0.69	0.62	12	0.60	0.82
13	0.54	1.04	13	0.26	1.18
14	0.31	0.72	14	0.23	0.79
15	0.44	0.83	15	0.58	0.58
16	0.31	0.50	16	0.97	0.50
17	0.23	0.97	17	1.28	1.08
18	0.53	0.68	18	0.73	1.15
19	0.49	1.09	19	0.38	0.53
20	0.35	0.81	[4]20	0.66	0.98
21	0.88	1.15	[4]21	0.44	0.42
22	0.15	0.48	22	0.94	0.57
23	0.19	0.57	23	0.68	0.81
24	0.33	0.36	24	0.40	0.85
25	0.35	0.47	25	0.26	0.43
26	0.12	0.23	26	0.15	0.53
27	0.58	0.80	27	0.99	1.16
28	0.62	0.65	[4]28	0.57	1.30
29	0.10	0.32			
30	0.66	0.49			
31	0.28	0.57			
32	0.06	0.74			
33	0.71	0.82			
34	0.58	0.60			
35	0.27	0.34			
36	0.37	0.81			
37	0.17	0.49			
	[5]0.46(a)	0.74(b)		0.49(a)	0.73(b)

[1] Thinned with Glowon® tree killer and Silvisar 510®, 1969.

[2] Thinned with Silvisar 550®, 1970.

[3] Arsenic determined by neutron activation, Washington State University, Pullman.

[4] Animal slaughtered for tissue arsenic residue analysis, fall 1970.

[5] Average values. Values with the same letter are not significantly different ($P>0.05$).

The results of analysis for arsenic in tissue of two cattle and one deer from the Mill Creek study area are in table 2.

Detectable residues of arsenic were only found in the hair of the two cattle and the deer from the Mill Creek study area. Lack of detectable residues in soft body tissues is expected because arsenic is rapidly dissipated from these tissues. The increase in arsenic concentration in hair from animal 28 was more than three times as great as the average increase for animals from the Mill Creek study area; but despite this, there were no detectable residues of arsenic in body tissues. The concentration of arsenic in hair from the deer is lower than the average for hair from cattle from the

Table 2--*Arsenic residues in tissues from two cows and one female deer which grazed in the Mill Creek study area during thinning operations*[1/]

Tissue	Animal 21	Animal 28	Deer
	- - - - - - ppm - - - - - -		
Hair	[2/]ND	1.3	0.3
Blood	ND	ND	[3/]---
Urine	---	ND	---
Liver	ND	ND	ND
Kidney	ND	ND	ND
Lung	ND	ND	ND
Heart	ND	ND	ND
Tongue	ND	ND	ND
Spleen	ND	ND	ND
Muscle	ND	ND	ND
Brain	ND	ND	---
Stomach contents	ND	ND	ND
Udder	ND	ND	---
Feces	---	---	ND

[1/] The area was thinned with Silvisar 550® during the summer of 1970. Cows were slaughtered in the fall of 1970 and tissues were analyzed at the Washington State Department Social and Health Services Laboratory, Wenatchee, Washington.

[2/] ND - Nondetectable means less than 0.20 ppm arsenic.

[3/] --- Not analyzed.

Mill Creek area. The presence of arsenic indicates that the deer received some exposure. It is not possible, however, to determine whether this represents arsenic from the thinning operation or arsenic which is naturally present in the environment.

NORRIS STUDY

Levels of arsenic in hair from exposed and unexposed animals are shown in table 3. I used paired t-tests on spring and fall residue levels in hair from (1) exposed cattle and (2) unexposed cattle. The results show no significant difference ($P>0.05$) between spring and fall values in the exposed group. In the unexposed group, on the other hand, the difference between spring and fall values is significant ($P<0.05$), indicating that the increase in arsenic concentration in hair is real. A t-test showed no difference ($P>0.05$) between arsenic levels in hair collected in the fall from exposed and unexposed cattle.

Table 3--*Arsenic in hair from cattle grazed in forest areas, Norris study*[1/]

Exposed Group[2/]			Control Group[3/]		
Animal	Spring	Fall	Animal	Spring	Fall
	- - - ppm - - -			- - - ppm - - -	
1	0.50	0.20	1	0.11	0.30
2	0.71	1.10	2	0.22	0.50
3	1.20	0.40	3	0.15	0.20
4	0.50	0.30	4	0.10	0.30
5	0.71	0.30	5	0.11	0.90
6	0.60	0.60	6	0.11	0.10
7	0.83	0.20	7	0.10	0.40
8	0.60	[4/]---	8	0.33	0.10
9	0.60	0.60	9	0.16	0.40
10	0.71	---	10	0.10	0.40
11	0.83	0.60	11	0.11	0.30
12	0.52	---	12	0.33	0.30
[5/][6/]	0.69	0.48		0.16	0.35

[1/] Arsenic determined at Washington Department of Social and Health Services, Wenatchee, Washington.

[2/] Animals grazed from June 18 to October 12, 1973, in a 900-acre grazing allotment. Approximately 700 acres were thinned with MSMA, 190 acres during the 1973 grazing season.

[3/] Animals grazed in untreated forest area.

[4/] --- Not analyzed; these animals were not resampled in the fall.

[5/] Average values.

[6/] Average value of 0.72 for the same nine animals sampled in the fall.

DISCUSSION

On the surface these results seem confusing, but they are not. The values reported in both studies are within a normal range of values for arsenic in hair from animals not specifically exposed to arsenic. Dickinson (1972, 1975) determined the toxicity characteristics of MSMA and cacodylic acid in cattle. He measured arsenic in hair before he began administering the herbicide and reported values of 2.1, 1.1, 0.8, 2.4, 0.9, and 1.0 ppm (average 1.4 ppm) arsenic for previously unexposed cattle. Dickinson's values are substantially higher than the mean values found by Maycumber or Norris for either exposed or unexposed cattle.

Dickinson (1972, 1975) also reported arsenic residues in hair from the same cattle after exposure to a diet including MSMA or cacodylic acid. The two animals receiving MSMA at 10 mg/kg per day had 1.4 and 3.3 ppm arsenic in hair after 10 days exposure. The three animals fed cacodylic acid at 10 mg/kg per day had 4.3, 2.6, and 2.0 ppm arsenic in hair after 10 days; arsenic accumulation continued with exposure. By 48 days, the arsenic concentrations were 32.8, 15.7, and 12.9 ppm, respectively. Rabbits receiving MSMA at 50 ppm in their diet showed a steady increase in arsenic residue levels in hair. Residues of 1.3 ppm, 2.4 ppm, and 3.6 ppm after 4, 7, and 12 weeks' exposure, respectively, were reported (Exon et al. 1974).

The levels of arsenic in hair detected by Maycumber and me apparently are not affected to an important degree by grazing in chemically thinned areas. The small changes in arsenic concentration detected with time or nature of exposure in these studies are not sufficient to elevate arsenic concentrations in hair to a diagnostically significant level.

Do these results indicate arsenic in hair is not a good indicator of arsenic exposure? No! Arsenic is everywhere in the environment. The natural levels of arsenic vary widely from nondetectable levels in some forest streams to 5 ppm in soil to more than 100 ppm in some shellfish (Norris et al. 1977, Schroeder and Balassa 1966). Man's activities cause some redistribution of arsenic. A copper smelter in Tacoma, Washington, emits approximately 2×10^5 kg As per year as As_2O_3 (Crecelius et al. 1975). All living things ingest at least small amounts of arsenic daily. The presence of detectable levels of arsenic in cattle hair before grazing in treated areas shows arsenic in hair is an indicator of exposure. Both the Dickinson (1972, 1975) and Exon et al. (1974) data show that the concentration of arsenic in hair increases with exposure to MSMA and cacodylic acid in the diet. Therefore, the data from both Maycumber's and my study indicate that (1) the organic arsenicals were handled and applied with sufficient care and (2) arsenic accumulation in understory vegetation was small enough so that arsenic in hair from cattle grazed in these chemically thinned areas did not increase beyond the normal range. I believe MSMA and cacodylic acid can be used operationally for thinning purposes without significant exposure to cattle grazing in thinned areas, even while the application is being made. Careful handling and application procedures are required, however.[2/]

[2/] Procedures for handling and application of MSMA and cacodylic acid in thinning programs developed by the Siuslaw and Colville National Forest are available from the author.

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The help of Clifford Lehman, Forestry Technician at Colville Ranger District, Colville, Washington, and Mr. John Neuman, formerly Chief Chemist, State of Washington, Department of Social and Health Services, Wenatchee, Washington, is gratefully acknowledged.

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USDA FOREST SERVICE RESEARCH NOTE

PNW-297 May 1977

ESTIMATING D.B.H. FROM STUMP DIAMETERS IN SECOND-GROWTH DOUGLAS-FIR

by

Robert O. Curtis, *Principal Mensurationist*

and

James D. Arney,[1/] *Mensurationist*

SEP 8 1977

ABSTRACT

Gives equations for estimating diameters at breast height of second-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) from measured stump diameters over bark and stump heights, based on measurements at 22 locations in western Oregon and Washington.

KEYWORDS: D.b.h. measurements, stump measurements, (-d.b.h. estimates, Douglas-fir, *Pseudotsuga menziesii*

[1/] James D. Arney is with Forestry Research Center, Weyerhaeuser Company, Centralia, Wash.

INTRODUCTION

In a yield study of coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), we found that some of our thinned plot records lacked a tally of trees cut in the initial thinning. In some cases there was a record of stump diameters of cut trees or such information could be obtained by field measurements. To reconstruct initial stand conditions, we needed appropriate regressions relating diameter at breast height (d.b.h.) to diameter and height of stump.

Similar needs to estimate tree d.b.h. from stump measurements occur in other research and management activities. Several people have developed estimating equations for specific stands or local areas; but we found no such equations (1) which were based on a sample distributed over a wide geographic area and a range of site conditions, (2) which applied to a wide range of diameters within second-growth stands, and (3) which explicitly included stump height as a variable.

Therefore, we have developed such equations from field measurements made by the Pacific Northwest Forest and Range Experiment Station's Olympia Laboratory and by Weyerhaeuser Company's Forestry Research Center.

THE DATA

Measurements were obtained from 22 field installations in western Washington and Oregon. Total number of trees measured was 454, with a range in d.b.h. from 2 to 42 inches. Maximum age was about 80 years; however, most trees were much smaller and younger than the maximum size and age.

Field procedure on each individual plot, within each installation, was:

1. Select a number (usually four) of normally formed Douglas-fir, across the range of diameters present.

2. Measure and record to nearest 0.1 inch:

   a. d.b.h. outside bark.
   b. d.o.b. (diameter outside bark) at 2.0 feet above ground level.
   c. d.o.b. at 1.0 foot above ground level.
   d. d.o.b. at 0.5 foot above ground level.
   e. d.o.b. at 0.25 foot above ground level (measurement omitted where root swell made measurement impracticable).

   All measurements were made with diameter tape.

ANALYSIS

1. *Individual installations*

   Regressions of the form

$$D.b.h. = a + b(d.o.b.) + c(d.o.b.)^2$$

   were fitted to the data from each installation, separately for each height of measurement, H = 2.0, 1.0, 0.5, and 0.25 ft. Usually, the squared term was nonsignificant. When present, curvilinearity was slight.

Regressions were plotted and superimposed. Inspection indicated that (a) lines for a given stump height were parallel or nearly so, and (b) although there might be small differences in elevation, possibly related to stand conditions, any such differences were too small to have much effect on practical applications.

2. *Individual heights of measurement*

All measurements for a given height were combined and a regression

$$D.b.h. = a + b(d.o.b.) + c(d.o.b.)^2$$

was fitted separately for each stump height. In each regression, the squared term was statistically significant but curvature was slight and apparently due mainly to a few of the largest trees.

3. *All data combined*

Scatter diagrams, calculated standard errors of estimate, and plots of residuals indicated that variance increased with diameter outside bark and with distance of the measurement point from breast height.

A weighted stepwise conditioned regression was fitted to all measurements combined, of the form:

$$\begin{aligned} w[d.b.h. - d.o.b.] = {} & wa_1(4.5\text{-}H) + wa_2(4.5\text{-}H)^2 \\ & + w[d.o.b.][b_1(4.5\text{-}H) + \ldots + b_4(4.5\text{-}H)^4] \\ & + w[d.o.b.]^2[c_1(4.5\text{-}H) + \ldots + c_4(4.5\text{-}H)^4] \\ & + w[d.o.b.]^3[d_1(4.5\text{-}H) + \ldots + d_4(4.5\text{-}H)^4] \end{aligned}$$

in which $w = 1/[(4.5\text{-}H)(d.o.b.)^{\frac{1}{2}}]$, a weighting factor which provided approximate uniformity of variance; and a, b, c, and d are regression coefficients.

The resulting equation can be written as:

$$D.b.h. = a + b(d.o.b.) + c(d.o.b.)^2 + d(d.o.b.)^3; \qquad (1)$$

where

$a = 0.12327 - 0.027392(H)$;

$b = 0.64885 + 0.27258(H) - 0.113191(H)^2 + 0.025339(H)^3 - 0.00217612(H)^4$;

$c = 0.0025583 - 0.0011370(H) + 0.00012634(H)^2$; and

$d = -0.000066158 + 0.000014702(H)$.

D.b.h. is diameter outside bark, in inches, at breast height.

D.o.b. is diameter outside bark, in inches, at point of stump measurement.

H is height above ground, in feet, at point of measurement.

Standard error of estimate (SEE) of this equation was 0.0402; i.e., $SEE_{d.b.h.}$ in inches = 0.0402 (4.5-H) $(d.o.b.)^{\frac{1}{2}}$.

Curves corresponding to equation 1 are shown in figure 1.

For individual height measurements, equation 1 reduces to:

H = 2.0 feet:

$$D.b.h. = 0.06848 + 0.90914(d.o.b.) + 0.00078965(d.o.b.)^2 - 0.000036755(d.o.b.)^3. \quad (2)$$

H = 1.0 foot:

$$D.b.h. = 0.09587 + 0.83141(d.o.b.) + 0.0015476(d.o.b.)^2 - 0.000051456(d.o.b.)^3. \quad (3)$$

H = 0.5 foot:

$$D.b.h. = 0.10957 + 0.75987(d.o.b.) + 0.0020214(d.o.b.)^2 - 0.000058807(d.o.b.)^3. \quad (4)$$

H = 0.25 foot:

$$D.b.h. = 0.11642 + 0.71031(d.o.b.) + 0.0022819(d.o.b.)^2 - 0.000062483(d.o.b.)^3. \quad (5)$$

Curves corresponding to the above equations are shown in figures 2-5, together with superimposed data points (a few points over 40 inches omitted). Relationships are virtually straight lines for trees under 24 inches; curvature is slight and is due to the few trees of larger size.

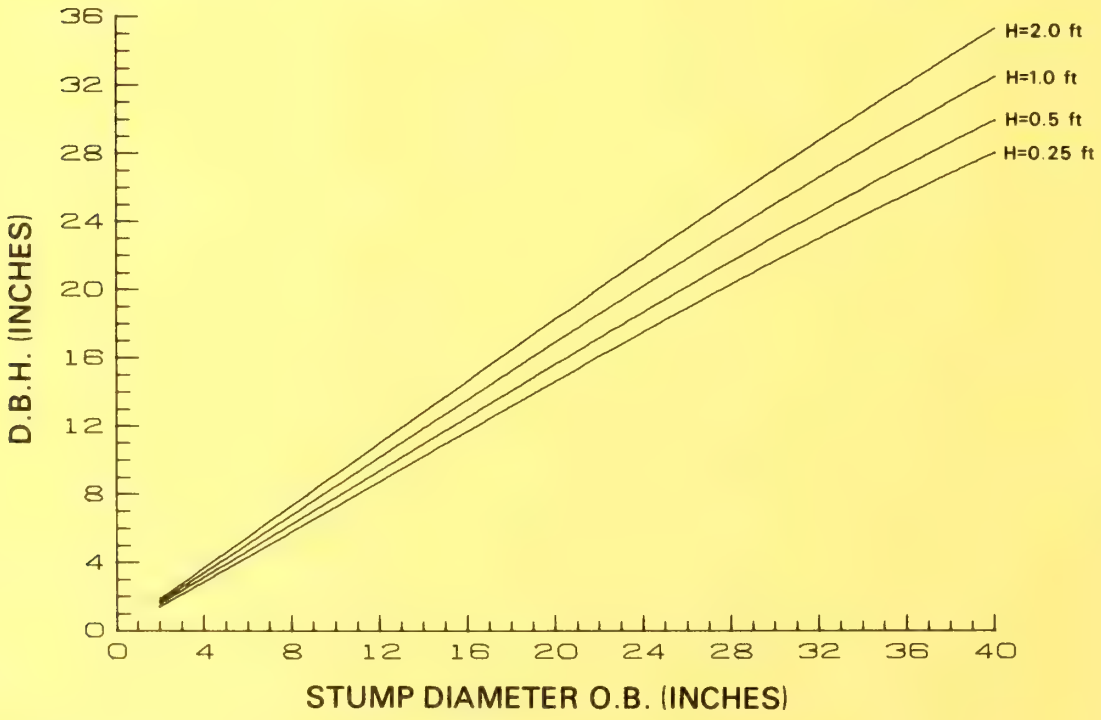

Figure 1--Curves of d.b.h. over stump d.o.b. and stump height (equation 1).

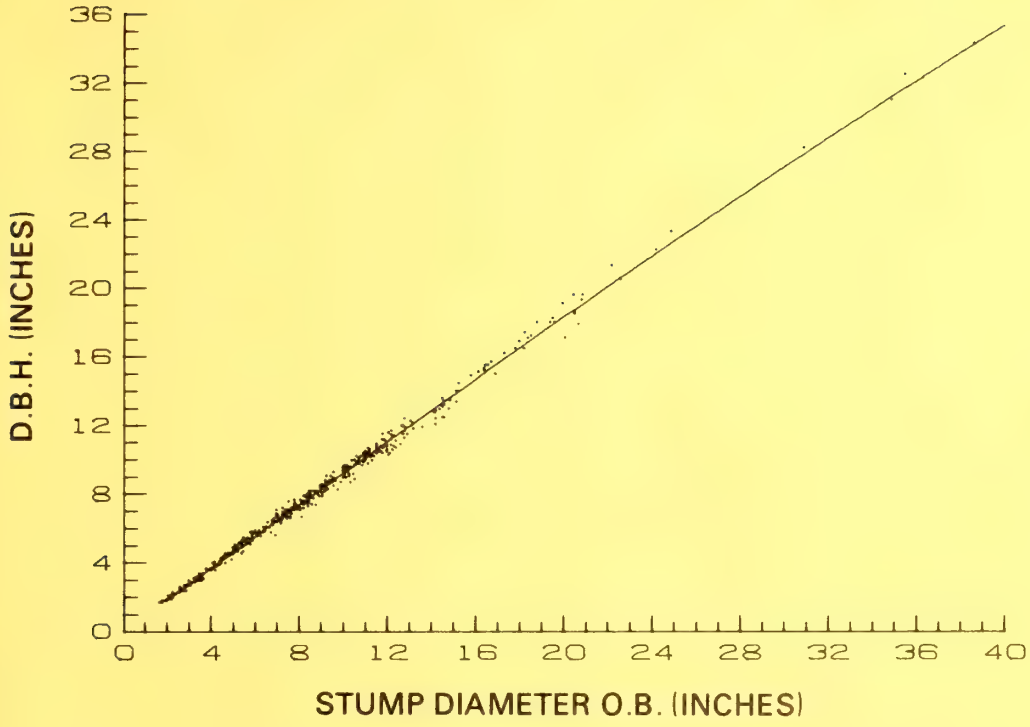

Figure 2--Data points and curve of d.b.h. over stump d.o.b. at 2.0 feet above ground (equation 2).

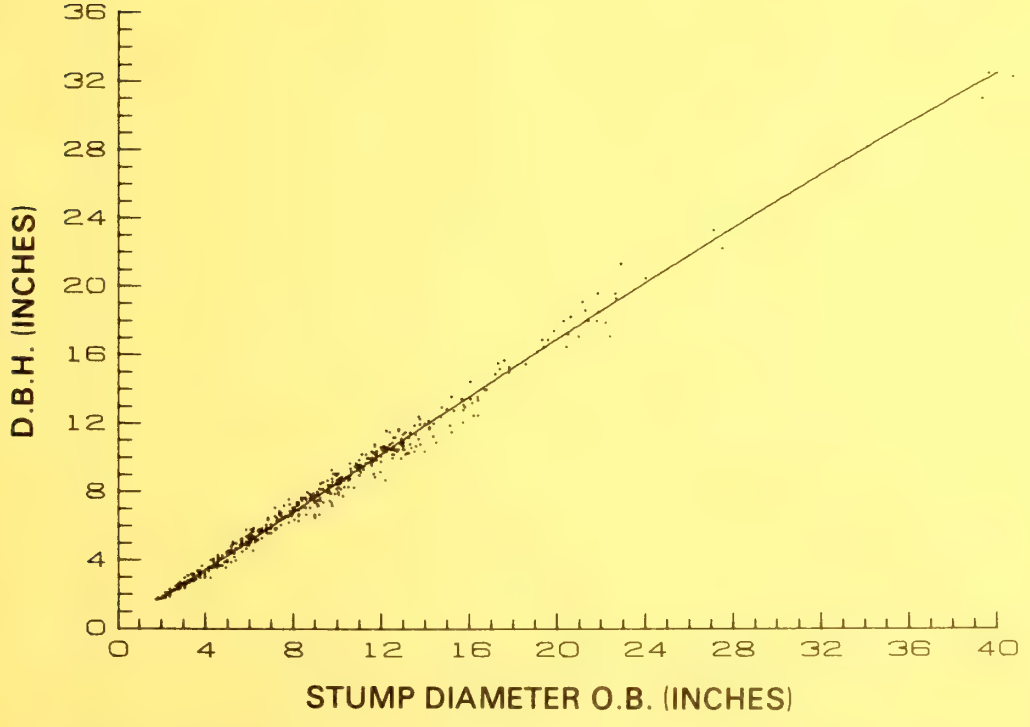

Figure 3--Data points and curve of d.b.h. over stump d.o.b. at 1.0 foot above ground (equation 3).

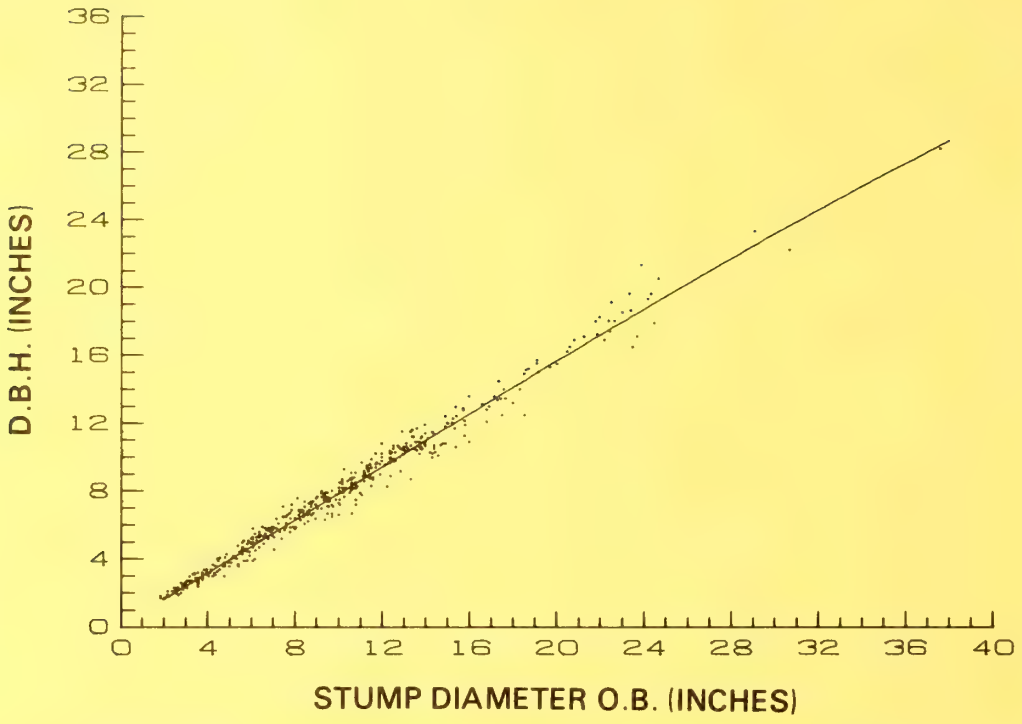

Figure 4--Data points and curve of d.b.h. over stump d.o.b. at 0.5 foot above ground (equation 4).

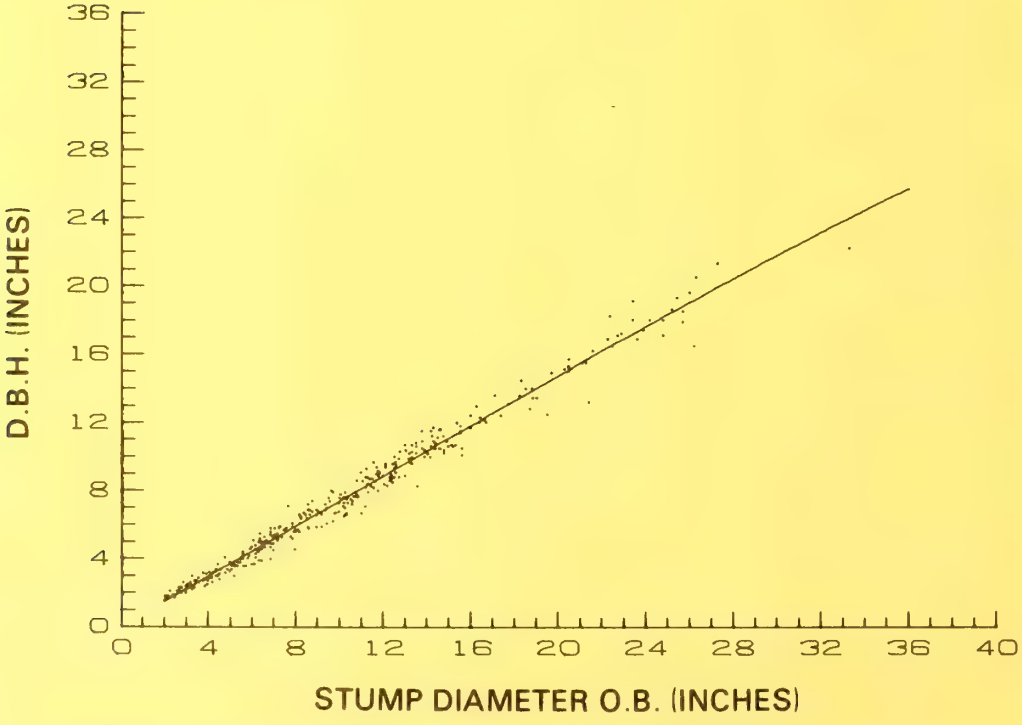

Figure 5--Data points and curve of d.b.h. over stump d.o.b. at 0.25 foot above ground (equation 5).

If stumps over 24 inches in diameter are excluded, the following simple linear regressions give nearly identical estimates:

Stump height = 2.0 feet:

$$D.b.h. = 0.04 + 0.9162\ (d.o.b.) \quad (6)$$

Stump height = 1.0 foot:

$$D.b.h. = 0.11 + 0.8374\ (d.o.b.) \quad (7)$$

Stump height = 0.5 foot:

$$D.b.h. = 0.10 + 0.7793\ (d.o.b.) \quad (8)$$

Stump height = 0.25 foot:

$$D.b.h. = 0.7369\ (d.o.b.) \quad (9)$$

Approximating the above by d.b.h./d.o.b. ratios leads to a nearly equivalent equation for stump diameters measured at variable heights:

$$D.b.h. = 0.8522\ (H^{-.1063})\ (d.o.b.) \quad (10)$$

APPLICATION

The relationships given are based on measurements made with diameter tape, over bark. Therefore, in applications, stump diameter measurements must be made over bark. If bark is partially or wholly missing, an appropriate ocular adjustment must be made at the time of measurement or bark thickness factors must be supplied.

If stumps are tallied by diameter over bark and height of stump, d.b.h. can be estimated by equation 1. In many situations, however, the range in size of stumps present in any one plot or stand is quite limited. It may be more convenient to measure or estimate stump diameters over bark at one of the standard heights used here (2.0, 1.0, 0.5, 0.25 ft) and then to use equations 2-5 or figure 1 to estimate the corresponding d.b.h.

If stumps do not exceed 24 inches in diameter, equations 6-9 will give nearly identical estimates and are more convenient. And, if measurements are to a variable stump height, equation 10 is only slightly less precise and is simple enough for ready use with a pocket calculator.

METRIC EQUIVALENTS

1.0 inch	=	2.54 cm
0.25 ft	=	7.62 cm
0.50 ft	=	15.24 cm
1.0 ft	=	30.48 cm
2.0 ft	=	60.96 cm
breast height = 4.5 ft	=	137.2 cm

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-298 May 1977

A FIELD GUIDE FOR STAND BASAL AREA, AVERAGE DIAMETER, AND TREE SPACING RELATIONSHIPS

by

James W. Barrett, *Research Forester*

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ABSTRACT

This guide is useful in manipulating forest stand density to silvicultural prescriptions in basal area. Reference equations and graphs are presented in English and metric units. Some examples of application are shown along with examples of other uses.

KEYWORDS: Stand basal area, diameter measurements (stem), stand density measures.

INTRODUCTION

Field foresters and technicians often manipulate forest stand diameter and basal area[1] to a given silvicultural prescription. This guide is a handy pocket reference for making the job easier.

The graph (fig. 1) of basal area in square feet as a function of average stand diameter in inches and trees per acre was developed by solving the following equation (0.005454154 from Husch, Bertram, Charles I. Miller and Thomas W. Beers, 1963. Forest Mensuration, 2nd ed., p. 100. Ronald Press Co., New York.):

$$B = 0.005454154 \times \bar{D}_g^2 \times TPA;$$

where,

$\bar{D}_g$ = diameter of tree of average basal area in stand (inches),

TPA = trees per acre, and

B = basal area of stand (square feet).

The guide describes stands up to 500 ft^2 per acre or 100 m^2 per hectare. Although basal areas this high are rare, they may occur in old-growth stands on high sites.

[1]The sum of cross-sectional areas of all tree stems 4.5 ft above the ground expressed in square feet or square meters on a given area.

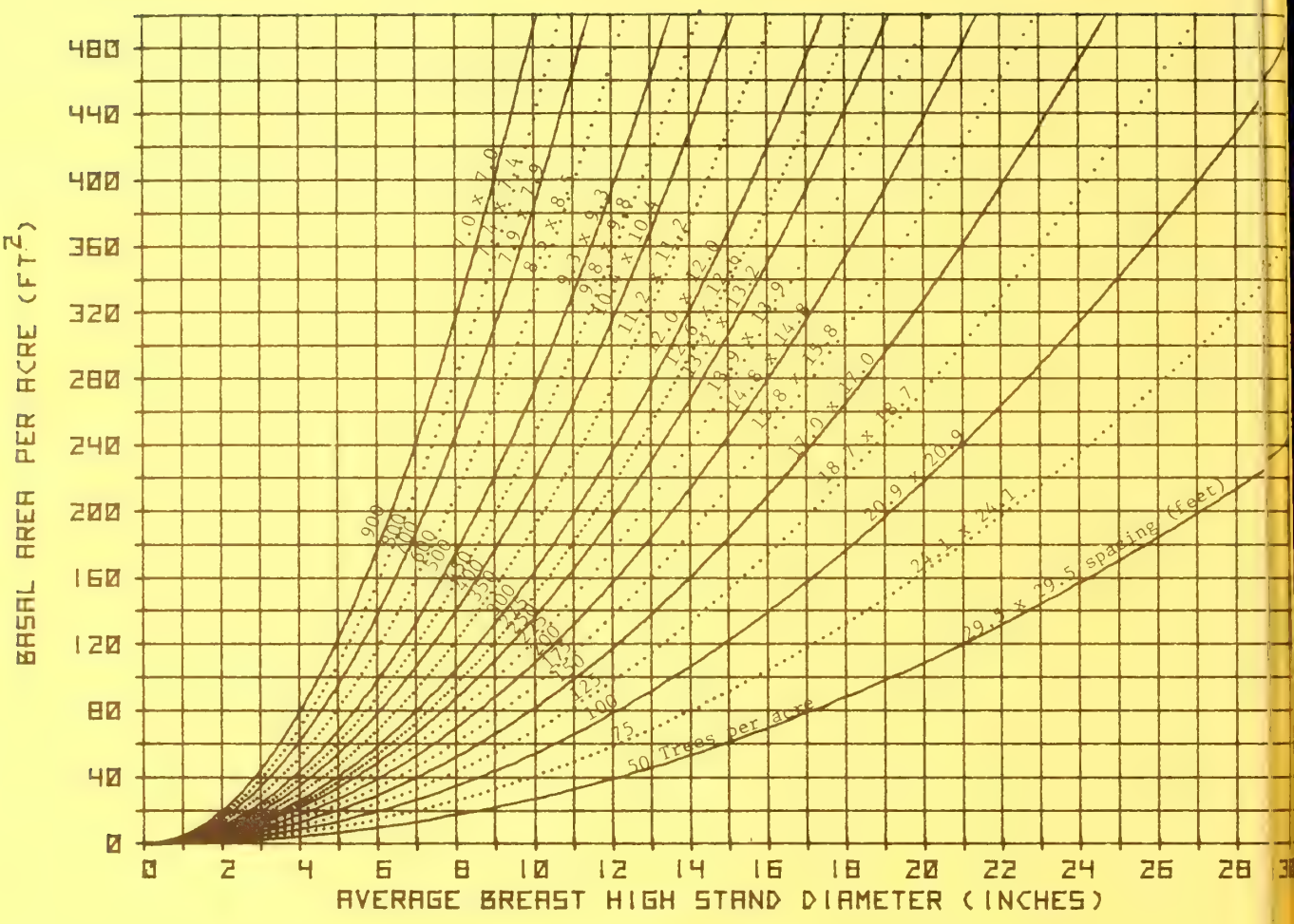

Figure 1.--Field guide for stand basal area, average d.b.h. and tree spacing relationships (English).

The graph (fig. 2) of basal area in square meters as a function of average stand diameter in centimeters and trees per hectare was developed by solving the equation

$$B = 0.00007853982 \times \bar{D}_g^2 \times TPH;$$

where,

$\bar{D}_g$ = diameter of tree of average basal area in stand (centimeters),

TPH = trees per hectare, and

B = basal area of stand (square meters).

The metric guide will help the reader who needs to interpret silvicultural and mensurational statistics expressed in the metric system.

To interpolate between curves, solve the equation for specific stand diameters and trees per acre.

Some examples of field use follow

COMMERCIAL THINNING

A common field use is the determination of the feasibility of

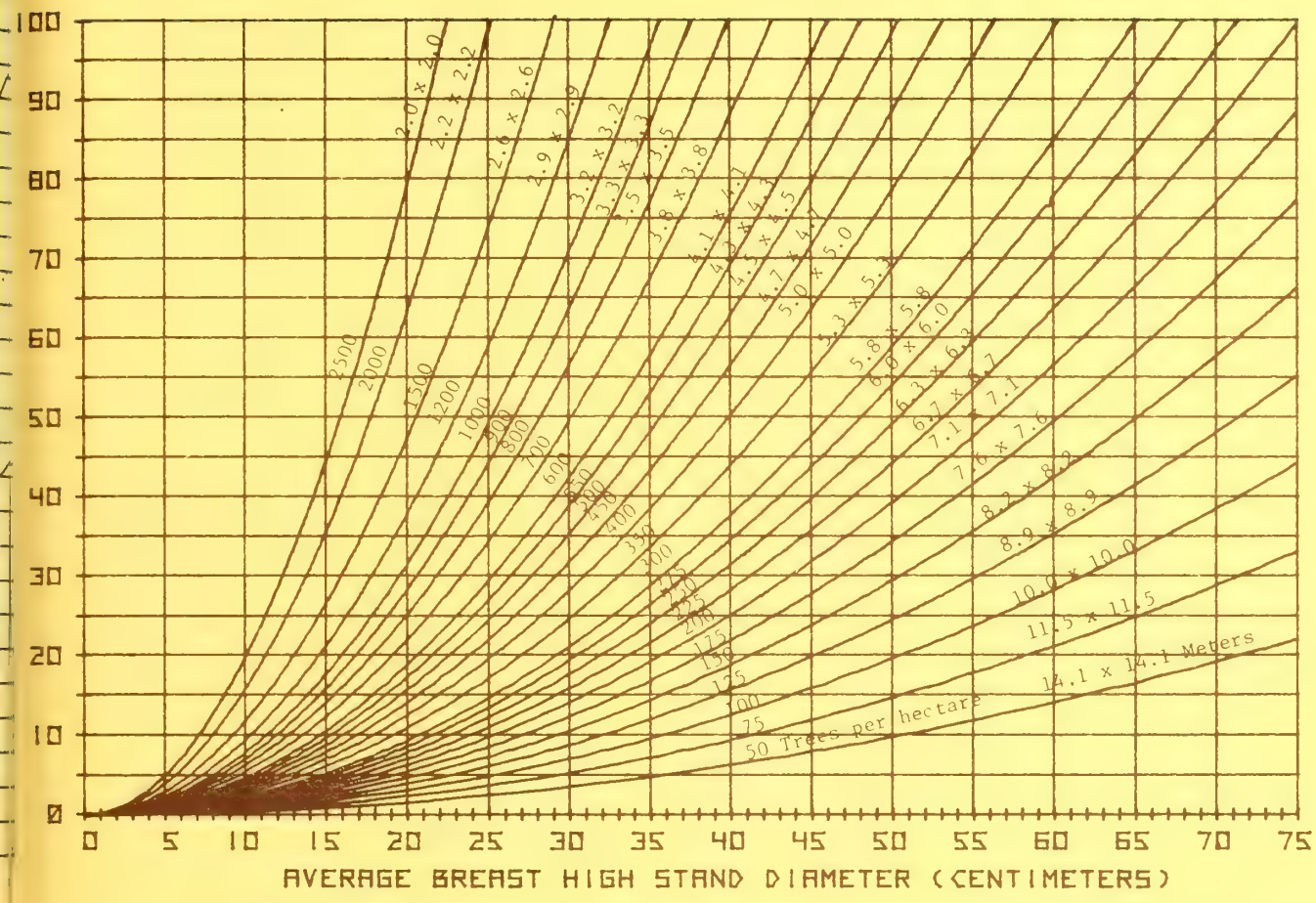

Figure 2.--Field guide for stand basal area, average d.b.h. and tree spacing relationships (Metric).

commercially thinning a young timber stand. Assume that stand diameter averages 15 inches with 150 trees per acre. With this diameter and density, basal area is slightly over 180 ft^2 (fig. 1). Trees under 10 in are not merchantable. We can then visualize that to reduce the stand to a residual basal area of 100 ft^2, 100 trees averaging 12-in d.b.h. (80-ft^2 basal area/acre) would have to be harvested. A cut tree tally in the stand might show that only 75 trees per acre (TPA) averaging 12 in could be cut without removing some trees slightly less than 10 in. From figure 1 we find that this would reduce basal area only 60 ft^2 (12-in d.b.h. and 75 TPA = 60-ft^2 basal area) indicating the need to mark additional trees in the larger size classes. After the desired cut-leave ratio is approximated using the graph in figure 1, a precise answer using the final stand tally can be calculated from the equations on the back of the field guide.

INITIAL TREE SPACING IN THINNING

Imagine a dense sapling stand to be thinned to 450 trees per acre. Also, assume that because of the probability of mountain pine beetle attack the stand cannot exceed 140 ft^2 of basal area before another commercial thinning. A horizontal line drawn across figure 1 at 140 ft^2 intersects the curved line representing 450 trees per acre at an average stand diameter of about 7.5 in. This intersect represents the average tree d.b.h. when the stand must be partially harvested. Therefore, if we leave this many trees, we assume that there will be a market for trees 8-in d.b.h. or less unless we are willing to thin from above. If a market for this size material will not exist, then we may look at the curve with fewer trees. Two hundred and fifty trees would indicate an average diameter of about 10 in when the stand contained 140 ft^2 of basal area.

INITIAL TREE SPACING IN A PLANTING PROJECT

A similar use might arise in planting a low site where we could not let the stand exceed a basal area of 120 ft^2. If 10 in is the anticipated minimum marketable size, then we should have about 225 trees just prior to commercial thinning. If we expect a 25-percent mortality rate and an additional 30 percent are slow growers or are forked or crooked, then 500 trees per acre should be planted. The 30-percent poor trees would be cut in pre-commercial thinning. From our graph, however, we can see that our 500 tree per acre stand coul not be allowed to exceed an aver diameter of about 6.5 in before precommercial thinning. Ideally precommercial thinning would be done much sooner when trees begi to express dominance.

PREDICTING APPROXIMATE CUTTING CY WITHIN A BASAL AREA MANAGEMENT BA

Suppose we want to make three commercial thinnings in a stand before final harvest. Basal area will be held between a management band of 80 and an extreme of 140 The first commercial pulpwood harvest reduced leave-tree basal area to 80 ft^2 and an average sta diameter of 10 in. We want to estimate the approximate time bef another commercial entry will be necessary. We see from the graph that the 10-in stand will grow to an average size of 13 in when the stand reaches the upper management limit of 140 ft^2. If the yield table predicts a 3-in per decade growth at this density and size, it will take about 10 years before the next harvest is due.

Other uses of the guide will come to mind as different problems arise.

-METRIC EQUATIONS-

The following formula can be solved in the field with most hand held electronic calculators.

$$\text{NUMBER OF TREES PER HECTARE} = \frac{10{,}000}{\text{SPACING}^2 \text{ (METERS)}}$$

OR

$$\text{SPACING (METERS)} = \sqrt{\frac{10{,}000}{\text{TREES PER HECTARE}}}$$

$$\text{BASAL AREA(B) (SQUARE METERS)} = .00007853932 \ \Sigma D^2$$

OR

$$B = \frac{\Sigma D^2}{12{,}732.398}$$

Where ΣD^2 is the sum of the squares of the diameters expressed in centimeters, and basal area is the total for those trees measured.

$$\text{AVERAGE STAND DIAMETER (CENTIMETERS)} \ \bar{D} = \sqrt{\frac{\Sigma D^2}{N}}$$

OR

$$\bar{D} = \sqrt{\frac{B}{.00007853982 \ N}}$$

Where N is the number of trees measured and B is the basal area per hectare.

FIELD GUIDE
FOR
STAND BASAL AREA, AVERAGE DIAMETER,
AND
TREE SPACING RELATIONSHIPS

by
JAMES W. BARRETT

This graphic guide may be used for rough approximations of stand characteristics where at least two dimensions are known. If more refined answers are desired, the equations on the back side of the guide will be useful.

METRIC

-EQUATIONS-

The following formula can be solved in the field with most hand held electronic calculators.

$$\text{NUMBER OF TREES PER ACRE} = \frac{43560}{\text{SPACING}^2 \text{ (FEET)}}$$

OR

$$\text{SPACING (FEET)} = \sqrt{\frac{43560}{\text{TREES PER ACRE}}}$$

$$\text{BASAL AREA(B) (SQUARE FEET)} = .005454154 \ \Sigma D^2$$

OR

$$B = \frac{\Sigma D^2}{183.3465}$$

Where ΣD^2 is the sum of the squares of the diameters expressed in inches, and basal area is the total for those trees measured.

$$\text{AVERAGE STAND DIAMETER (INCHES)} \ \bar{D} = \sqrt{\frac{\Sigma D^2}{N}}$$

OR

$$\bar{D} = \sqrt{\frac{B}{.005454154 \ N}}$$

Where N is the number of trees measured and B is the basal area per acre.

FIELD GUIDE
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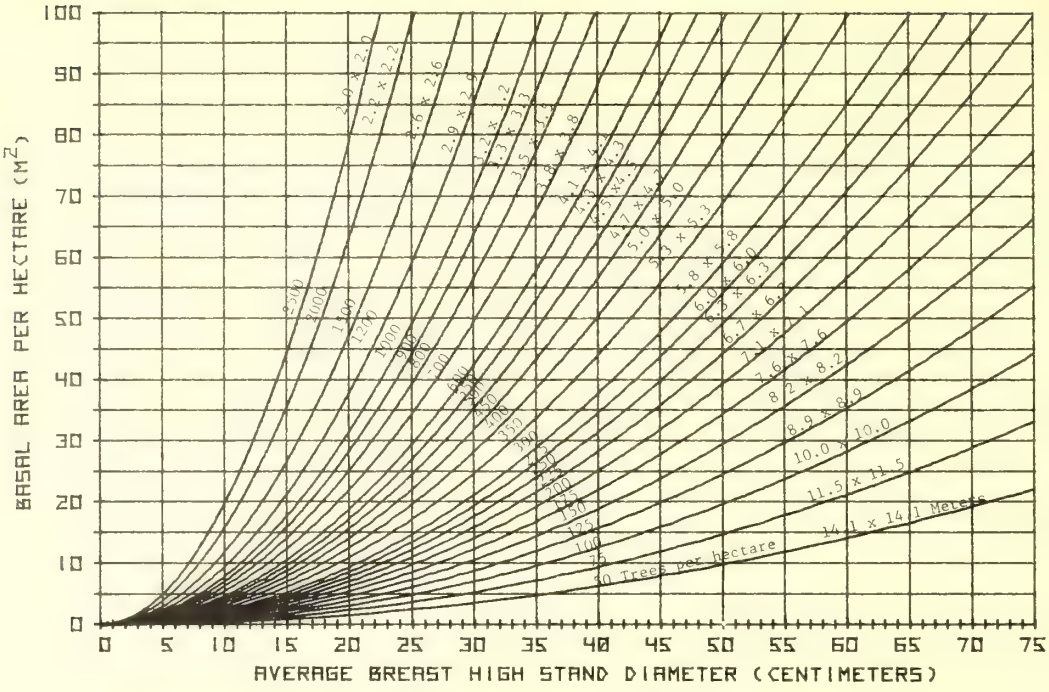
This graphic guide may be used for rough approximations of stand characteristics where at least two dimensions are known. If more refined answers are desired, the equations on the back side of the guide will be useful.

ENGLISH

FIELD GUIDE FOR
STAND BASAL AREA, AVERAGE DBH
AND TREE SPACING RELATIONSHIPS



FIELD GUIDE FOR
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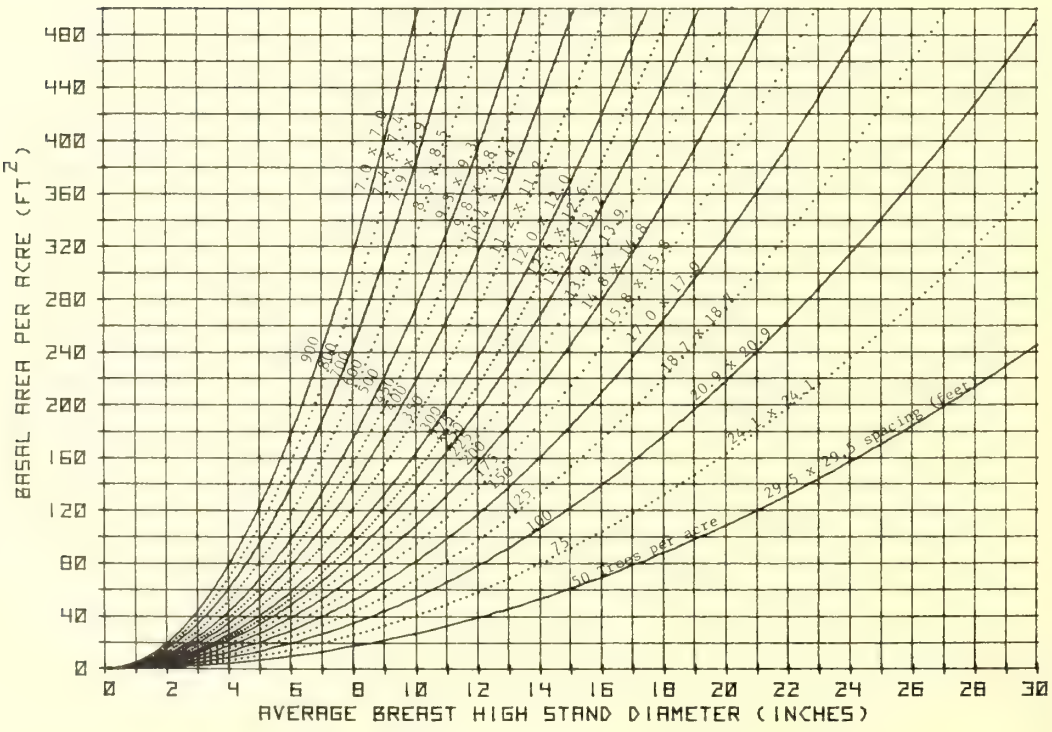

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

3 79 PNW-299

PNW-299 June 1977

AUG 19 1977

MICRO-ORGANISMS FROM THE PITH REGION OF SUPPRESSED GRAND FIR UNDERSTORY TREES

by

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and

Anita Hutchins, *Microbiologist*

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ABSTRACT

Basidiomycetes, some known to be capable of causing decay, were isolated from the stem pith and encased branch pith regions in 13 of 16 suppressed grand fir understory trees. The woody tissues from which the fungi were isolated were neither discolored nor decayed. The future decay hazard of these infections merits additional study to determine whether or not suppressed grand fir understory should be retained as forest reproduction.

KEYWORDS: *Decay fungi (wood), decay hazard, bacteria (-wood deterioration, regeneration (natural), natural regeneration, nitrogen fixation, suppression (tree), understory layer, pith core structure, grand fir,* Abies grandis, *Indian paint fungus,* Echinodontium tinctorium.

INTRODUCTION

The site and mode of infection of true firs and hemlocks by the Indian paint fungus, *Echinodontium tinctorium* Ell. & Ev., have been speculated about by forest pathologists for years (Maloy 1967). Branch stubs and wounds have been reported to be infection courts for the Indian paint fungus (Meinecke 1916, Thomas 1958, Boyce 1961, Kimmey and Bynum 1961). Etheridge et al. (1972) have shown that *E. tinctorium* can infect western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) through dead adaxial branchlets less than 0.04 inch (1 mm) in diameter on living, shade-suppressed branches. Reduced growth due to suppression slows healing of these small twig traces to allow infection. When infected branchlet stubs heal over, the fungus becomes dormant (Etheridge et al. 1972). Apparently *E. tinctorium* may remain in this condition for decades without causing discoloration or decay (Etheridge et al. 1972). Injuries, such as logging wounds, frost cracks, and large branch stubs, are hypothesized to reactivate dormant *E. tinctorium* infections (Etheridge and Craig 1976).

Grand fir (*Abies grandis* (Dougl.) Lindl.) and white fir (*A. concolor* (Gord. & Glend.) Lindl.) are also important hosts for the Indian paint fungus. Suppressed grand and white firs, often of advanced ages, are allowed to regenerate thousands of acres of commercial forest land in eastern Oregon and Washington. Forest managers are concerned that this trend may lead to future decay problems.

This exploratory study was made to see if infections of *E. tinctorium*, or other decay fungi, are present in stem pith and branchlet pith tissues encased in stems of suppressed grand fir regeneration.

METHODS AND MATERIALS

The study trees were in the understory of a 250-year-old virgin, unburned stand of grand fir and Engelmann spruce (*Picea engelmannii* Parry) at 4,500 feet (1 371.6 m) elevation near the junction of Little Baldy and Deardorff Creeks, Prairie City Ranger District, Malheur National Forest in Oregon. All trees were within 100 feet (30.5 m) of mature grand firs bearing *E. tinctorium* sporophores.

The study trees were cut with an axe at ground line. All branches were clipped off near the main stem. Stem sections were placed in plastic bags and taken to the laboratory where they were stored at 2°C. Stem diameter and age by ring count were determined at the ground level cut. The trees ranged in age from 39 to 70 years (average 57); 0.7 to 1.6 inches (1.8-4.1 cm) in diameter (average 0.9 in or 2.3 cm) at the ground line; and were 3 to 6.3 feet (0.9-1.9 m) in height (average 4.8 ft or 1.5 m). Nonsuppressed grand fir reproduction was not available for comparison.

Each tree stem was dissected into 4-inch (approximately 10-cm) sections. These were split in half to expose stem pith and as many buried twigs as possible. Small wood chips were aseptically removed from freshly exposed stem pith and pith region of encased twigs, placed on 2.5-percent malt agar slants in culture tubes, and incubated at 20°C. Whether twigs sampled were living or dead or, if dead, whether they were completely grown over (occluded) was not noted.

Tubes were checked periodically for growth of micro-organisms; those without growth were discarded after 6 weeks. Organisms that grew from the wood chips were examined and assigned to the following groups: bacteria, yeasts, imperfect fungi, and Basidiomycetes. Attempts were made to identify the Basidiomycetes and some commonly occurring imperfect fungi, but not the bacteria or yeasts.

Bacterial isolates were tested for nitrogen-fixing capability by the acetylene reduction technique according to Aho et al. (1974) by Arthur D. Nelson under the direction of Harold J. Evans, Department of Botany and Plant Pathology, Oregon State University, Corvallis, Oregon.

RESULTS AND DISCUSSION

More than 1,200 isolation attempts were made from stem pith and pith regions of twigs that were exposed when stems were split (table 1). Micro-organisms were isolated in 42 percent of the stem pith and in 66 percent of the twig pith isolation attempts.

Table 1--*Types of micro-organisms*[1] *isolated from stem and twig pith regions of 16 suppressed grand fir understory trees*

Pith location	Isolation attempts	No growth	Bacteria	Yeasts	Imperfect fungi	Basidiomycetes
	Number	- - - - - Percent of total isolation attempts - - - - -				
Main stem	428	58	30	2	9	1
Encased twigs	786	34	11	4	44	7
Total or average	1,214	42	18	4	31	5

[1] Dorothy Chu at the Pacific Forest Research Center, Victoria, British Columbia, and Frances L. Lombard at the Center for Mycology Research, Forest Products Laboratory, Madison, Wisconsin, kindly assisted the authors in identifying the fungi.

Bacteria were the most commonly isolated micro-organisms from the stem pith region (table 1). Of the bacteria isolated, 43 percent were able to reduce acetylene to ethylene, which is qualitative evidence that they possess nitrogenase. Bacteria capable of fixing atmospheric nitrogen have been isolated from decay columns in living white fir trees in Oregon (Aho et al. 1974). This is the first report, to the best of our knowledge, of

the occurrence of these potentially important bacteria in apparently healthy trees. These findings also suggest that small twigs may be important invasion sites for the nitrogen-fixing bacteria.

Imperfect fungi were the most common (44 percent of all isolation attempts) micro-organisms isolated from the pith region of twigs encased in the main stem (table 1). Commonly isolated imperfect fungi included: *Kirchsteiniella thujina* (Peck) Pom. & Ether., *Retinocyclus abietis* (Crouan) Groves & Wells, *Zythia resinae* (Ehr. ex Fr.) Karst., *Rhinocladiella* sp. and *Dermea* sp. Only a few isolations of *Ascocoryne sarcoides* (Jacq. ex S.F. Gray) Groves & Wils. were made in this study. This fungus is commonly isolated from medullary tissues in western hemlock stems, and it is thought to be an effective competitor of *E. tinctorium* for this habitat (Etheridge and Craig 1976).

Slightly more than 5 percent (63 of 1,214) of all cultural attempts resulted in isolation of Basidiomycetes with clamp connections (table 1). They were isolated from 13 of the 16 study trees. The tissues from which Basidiomycetes were isolated were not obviously discolored or decayed, indicating that the infections were either recent (young) or dormant.

The majority (45 of 63) of Basidiomycetes isolated could not be identified. They were placed into four groups based on cultural characteristics. The most commonly occurring group (39 of the 45 unidentified isolates) was unidentified basidiomycete "A," which was isolated from 10 of the 16 study trees. Fungus "A" was frequently isolated from encased twigs less than 0.08 inch (2 mm) in diameter, which, according to Etheridge et al. (1972), are major infection sites for *E. tinctorium*. Possibly fungus "A" competes with *E. tinctorium* for these habitats in grand fir as *A. sarcoides* does in western hemlock. We are trying further to identify this fungus and are studying its decay capability and competitive relationship with *E. tinctorium*.

Nearly 29 percent (18 of 63) of the Basidiomycete isolates could be identified, and these were from seven study trees. The species include: *E. tinctorium* (one tree), *Phlebia rufa* (Pers. ex Fr.) M. P. Chris. (four trees), *Fomitopsis annosa* (Fr.) Karst. (one tree), *F. pinicola* (SW. ex Fr.) Karst. (two trees), *Ganoderma applanatum* (Pers. ex Wallr.) Pat. (one tree), and *Coriolus* (*Polyporus*) *versicolor* (L. ex Fr.) Quél. (one tree).

Only *E. tinctorium* and *F. annosa*, of the identified Basidiomycetes, are known to cause significant amounts of decay in living, mature grand firs. Survival ability of Basidiomycetes, other than *E. tinctorium*, after infection sites are grown over, is unknown. Basidiomycetes infecting Douglas-firs (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) through pruning wounds died soon after the wounds healed (Childs and Wright 1956).

These data indicate that a potential decay problem exists in suppressed grand fir understory trees. Studies are needed to determine: (1) to what extent advance grand fir regeneration is

infected by *E. tinctorium* and other decay fungi, (2) if degree of infection is related to length of suppression, (3) whether or not dormant infections become active and cause decay when trees are released, and (4) what factors reactivate these infections.

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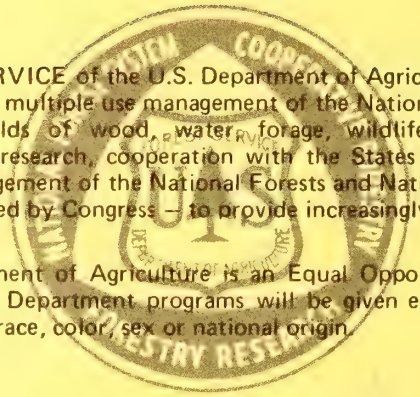

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USDA FOREST SERVICE RESEARCH NOTE

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FLOW RATES AND CHARACTERISTICS OF DIMILIN, DYLOX 1.5, ORTHENE 75S, AND SEVIN 4-OIL[1/]

by

James Wernz and George P. Markin[2/]

DEC 1 0 1977

Abstract

Flow rates are presented for Dimilin, Dylox 1.5, Orthene 75S, and Sevin 4-oil at five pressures and four temperatures using three standard T-jet nozzles. Physical properties of settling, density, and viscosity and handling characteristics are also discussed.

KEYWORDS: Insecticides, chemical control (-forest pests, Dimilin, Dylox, Orthene, Sevin.

[1/] The research reported here was financed in whole or part by the USDA Expanded Douglas-fir Tussock Moth Research and Development Program.

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INTRODUCTION

In western North America the Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), is a major pest of fir forests and can cause extensive tree mortality and growth loss.[3/] One objective of the USDA Expanded Douglas-fir Tussock Moth Research and Development Program is to develop and test chemical insecticides capable of controlling the tussock moth and suitable for aerial application under mountainous forested conditions.[4/] The most promising materials tested to date are Dimilin®, Dylox 1.5®, Orthene 75S®, and Sevin 4-oil®. The usual method of applying liquid chemicals against the tussock moth and other forest defoliators has been aerial application by helicopter or fixed-wing aircraft equipped with hydraulic spray nozzles and flat fan, T-jet nozzle tips (Spraying Systems Co., Wheaton, Ill.).

When such systems are used in the field, the number and size of the nozzle tips must be determined to produce the desired flow rate for a specific insecticide. The flow rate for a given type of nozzle, the number of nozzles used, and the speed of the aircraft determine the amount of material applied per acre. Unfortunately, we have no simple standard method of establishing the flow rate of nozzle tips for a new insecticide. Each material has a distinctive flow rate which changes with the boom pressure, the amount of diluent added to the material, and sometimes with the temperature. Knowing the flow rate of each material is, therefore, of major importance in planning and conducting a control program. This information is usually determined for each aircraft at the time of the program and is a time consuming, difficult, and, under field conditions, often an inexact procedure.

Standardized equipment was used under laboratory conditions to evaluate each of the four candidate materials to determine flow rate (volume per minute) through a series of flat fan nozzle tips at a range of temperatures, pressures, and dilutions likely to be encountered in the field under standard operating conditions. We planned to present the results of these tests, along with general observations of mixing and handling properties of the four materials, in a series of figures. A pilot, knowing the speed of his aircraft and the volume of materials to be delivered per acre, refers to these figures to determine the flow rate for each material for a given size nozzle, and determines the number of nozzles, the boom pressure, and nozzle size necessary to meet his application rates.

[3/] Wickman, Boyd E., Galen C. Trostle, and Paul E. Buffam. 1973. Douglas-fir tussock moth. USDA For. Serv. For. Pest Leafl. 86 (rev.), 6 p., illus.

[4/] This paper reports work involving chemical insecticides. It does not include recommendations for their operational use nor does it imply that uses discussed here are registered. All uses of pesticides must be registered by appropriate State and Federal Agencies before they can be recommended.

MATERIALS AND METHODS

Ten-gallon (38-liter) and three-gallon (11-liter) pressure tanks (similar to carbonated drink fountain tanks) were fitted with two pressure hoses. One hose was connected to a nitrogen gas cylinder with a pressure regulator, the other to a spray chamber. The spray chamber consisted of a Fiberglas® sink and a clear Plexiglas® lid (fig. 1). A 1/2-inch (1.3-cm) pipe was inserted into the chamber and fitted with a pipe "T" to hold the nozzle assembly inside the chamber. A pressure gage and spray valve were fitted onto the pipe outside the chamber (fig. 2).

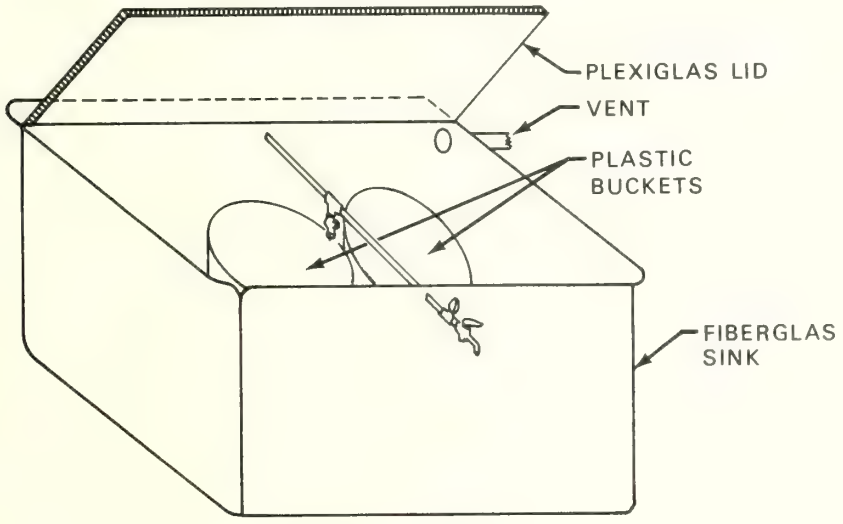

Figure 1.--Spray chamber.

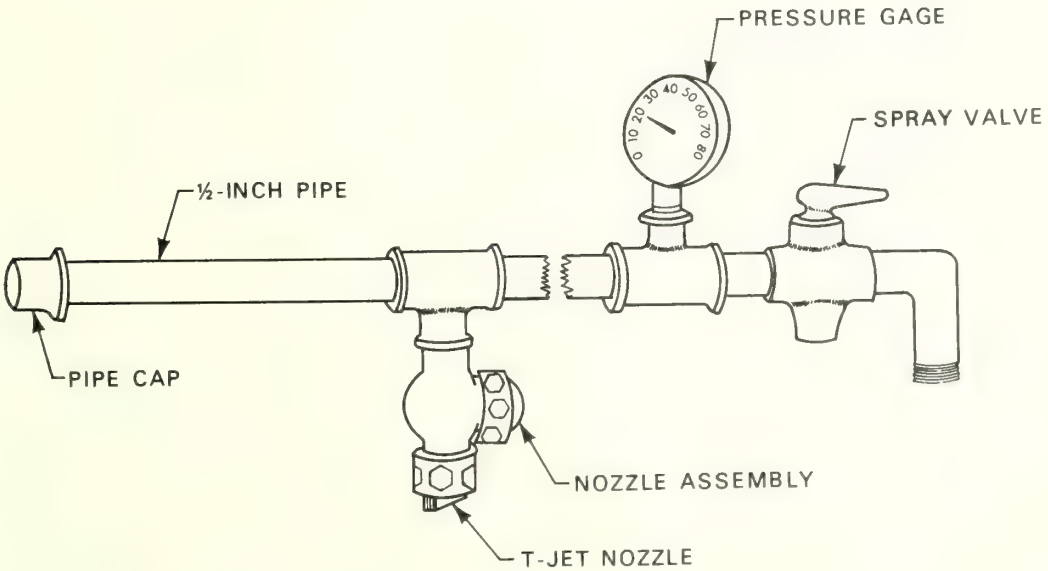

Figure 2.--Spray assembly.

During the tests, the chamber was kept under partial negative pressure by fitting a 1-inch (2.54-cm) Tygon® tube onto the chamber and onto a trap with a spun glass filter (fig. 3). An additional tube vented the trap outdoors and was fitted with an air pressure ejector to draw air from the spray chamber through the trap. It also kept spray mist and odors outside the room. The ejector had no moving parts that could cause sparks from friction.

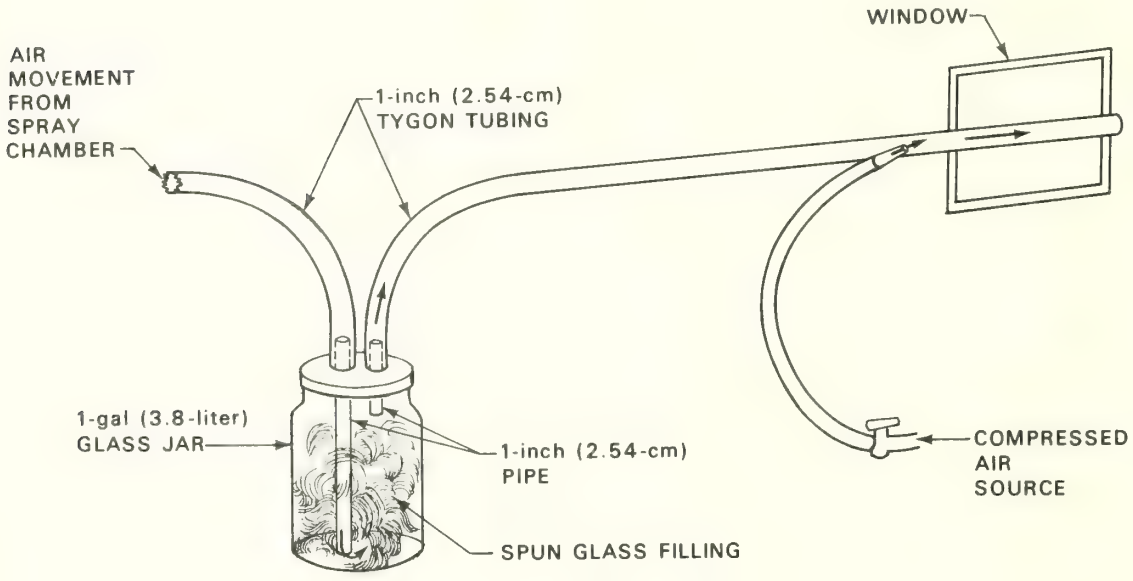

Figure 3.--Air vent system.

The formulation was mixed to the desired concentration, placed in the tank, and pressurized with nitrogen gas. Two plastic buckets were placed on the floor of the spray chamber, the spray valve was turned on, and the pesticide was sprayed through the system. An operator adjusted the pressure with a regulator on the nitrogen tank to compensate for friction in the nozzle supply system. Tank pressure was frequently 10-20 psi (51.71-103.4 cm Hg) higher than nozzle pressure.

When the pressure was established, the formulation was sprayed into plastic buckets for three 1-minute periods and then measured into a graduated cylinder. The three collections were averaged to estimate gallons per minute (ml/min) delivered through the nozzle.

The pesticides were tested at the following concentrations of active ingredient (ai), nozzle sizes, temperatures, and pressures:

Pesticide concentrations

Dimilin (TH6040)	1, 2, 4 ounces ai/gal (0.007, 0.015, 0.029 kg/liter) in water
Dylox 1.5	1.5 pounds ai/gal (0.180 kg/liter) of carrier as supplied by manufacturer
Orthene 75S	1/2, 1, 2 pounds ai/gal (0.059, 0.119, 0.238 kg/liter) in water
Sevin 4-oil	2, 3, 3.6 pounds ai/gal (0.238, 0.357, 0.428 kg/liter) in diesel fuel
Water, for comparison	
Nozzle sizes	800067, 8002, 8010
Temperatures	30, 40, 50, 60 °F (-1.1, 4.4, 10, 15.5 °C)--constant pressure of 40 psi (206.9 cm Hg)
Pressures	20, 30, 40, 50, 60 psi (103.4, 155.1, 206.9, 258.6, 310.3 cm Hg)--constant temperature of 55 °F (12.77 °C)

Low temperatures were obtained by placing the 3-gallon (11-liter) tank in an ice-rock salt bath. Other temperatures were maintained when the large tank was placed in a controlled warm water bath.

Viscosity was measured with a Brookfield® Viscometer Model VI and is expressed as centipoises (cps). Density was measured with volumetric flasks and a Mettler® balance.

Observations were also made on general physical characteristics. The results are summarized in the following pages.

Dimilin (TH6040)

Generally, Dimilin performed well in the spray system. It mixed well when first mixed as a slurry and then diluted (procedure recommended by Thompson-Hayward Chemical Co.). The particle size appeared uniform, and it was free of large foreign particles so filter screens did not plug up. The mixture had no objectional odor, sprayed well at the various temperatures, and did not freeze at 30 °F (-1.1 °C). At lower temperatures, however, it did freeze on the sides of the tank.

At the three concentrations, the flow rates of the different nozzles were virtually identical for temperature and pressure variations (figs. 4 and 5). This will simplify field operations if altering the concentraton of spray from one plot to another is necessary, because the spray system will not need to be changed.

In the field, Dimilin did not need to be mixed into a slurry before final dilution if:

1. The mixing tank was equipped with strong agitators. Ideally, this would be a recirculating pump plus two or three power-driven triblade paddles.

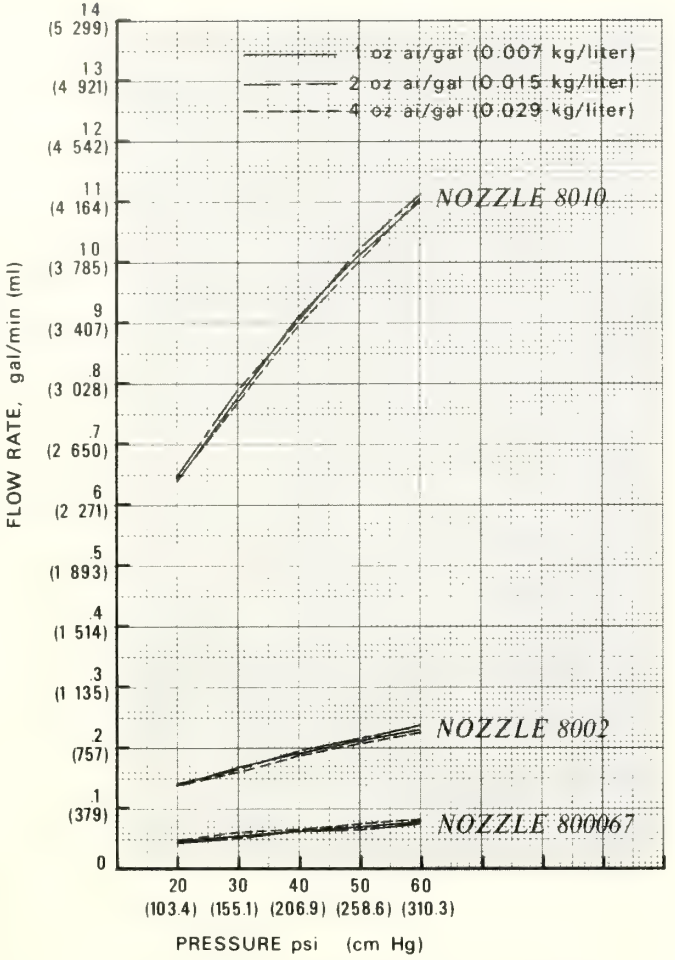

Figure 4.--Flow rates of Dimilin (TH6040) at various pressures.

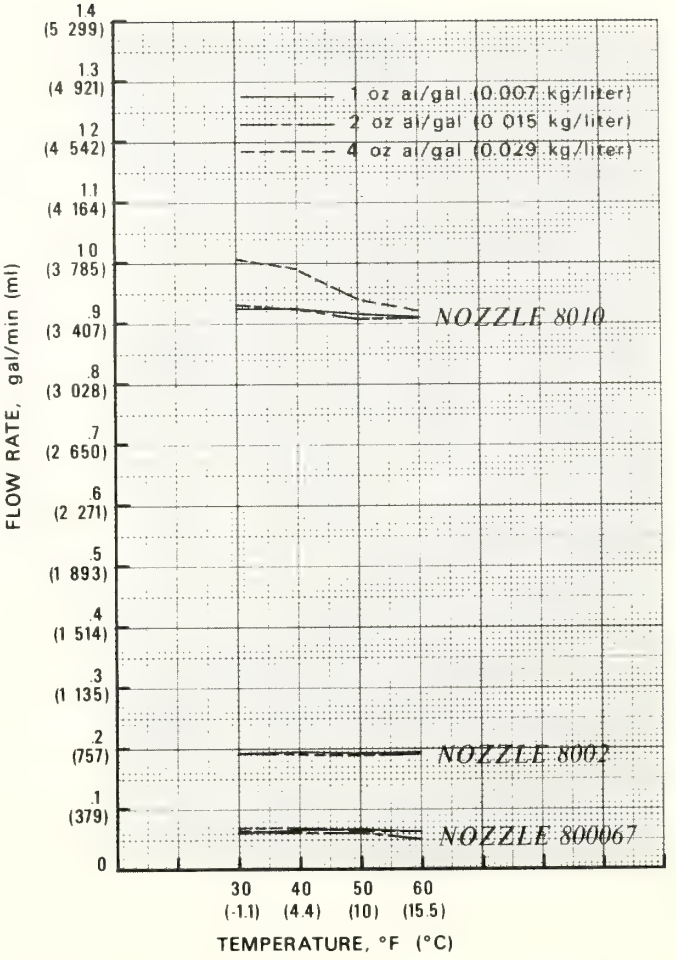

Figure 5.--Flow rates of Dimilin (TH6040) at various temperatures.

The paddle agitator may be sufficient if the material is added slowly. A strong recirculating pump also worked for up to approximately 8 ounces ai per gallon (0.59 kg/liter) of water.

2. The material on the liquid surface is mixed in by hand. As a safety precaution, all other agitators (especially paddles) should be stopped before the mixture is stirred by hand.

Dimilin foamed when agitated. This provided a surface layer that collected a portion of the powder and prevented it from going into solution. Some of this powder formed clumps that floated on top of the foam, but the clumps were dissolved when the foam was manually stirred into the liquid.

Settling was the most objectionable characteristic exhibited by Dimilin. Table 1 shows the amount of material settled out over a 12-day period. Most

Table 1--*Settling measurements of Dimilin (TH6040) in water (250-ml samples)*

Concentration	Settling time			
	24 hours	48 hours	6 days	12 days
	Milliliters			
4 oz/gal (0.029 7 kg/liter)	50	46	42	43
2 oz/gal (0.014 8 kg/liter)	22	17	18	20
1 oz/gal (0.007 4 kg/liter)	10	11	12	12

of this settling occurred within the first 24 hours. The settled material compacted with time and became extremely cohesive and difficult to resuspend. Resuspension required scraping or stirring of the material at the bottom of the tank to loosen the Dimilin and then agitating the mixture. Agitation of the solution with the pump or paddles left settled material in the corners of the tank.

In practice, the formulation should be mixed immediately before spraying to minimize settling problems. If a large amount is mixed and cannot be sprayed immediately, we recommend that the solution be in constant agitation until it can be loaded into the spray equipment and sprayed.

If Dimilin is to be used in the aircraft spray system again the following morning, the system should be flushed with water immediately after spraying to avoid plugging of the lines from settling of material.

Density and viscosity measurements of Dimilin (TH6040) are as follows:

Density

4 oz/gal (0.029 7 kg/liter) = 8.65 lb/gal (1.038 g/cm^3)
2 oz/gal (0.014 8 kg/liter) = 8.43 lb/gal (1.011 g/cu^3)
1 oz/gal (0.007 4 kg/liter) = 8.19 lb/gal (0.982 1 g/cu^3)

Viscosity @ 20 °C

4 oz/gal (0.029 7 kg/liter) = 7 cps
2 oz/gal (0.014 8 kg/liter) = 6 cps
1 oz/gal (0.007 4 kg/liter) = 5.5 cps

Dylox 1.5

Dylox 1.5 was tested as supplied by the manufacturer since application plans did not call for further dilutions (figs. 6 and 7). It handled well under most conditions. The exception was at 30 °F (-1.1 °C) with the 800067 nozzle and 100-mesh screens which continually plugged. The material causing this was not saved. It was presumed to be congealed Dylox or carrier. The plugging was not evident with other nozzles or temperatures and was not considered a severe problem since neither the 30 °F (-1.1 °C) temperature nor the 800067 nozzle is used often in the field.

We had some difficulty in obtaining pressures of 40 psi (206.9 cm Hg) and higher, but we thought this was a problem arising from the construction of the system combined with the viscosity of Dylox (see "Limitations of Design").

Settling, density, and viscosity of Dylox 1.5 (1.5 lb ai/gal or 0.18 kg ai/cu^3) were as follows:

Settling (250 ml sample)

8 ml clear fluid on top
30 ml paste on bottom
Remainder, uniform color (white) and consistency

Density

9 360 g/cu^3 or 7.803 lb/gal

Viscosity

121 cps at 20 °C

The pastelike material that settles out was easily stirred back into suspension, as was the clear fluid that rose to the top.

Earlier reports (personal communication, Markin, Orchard, and Neisess, Forestry Sciences Laboratory, Corvallis, Oregon, 1975) indicated that before 1974 formulations of Dylox "clabbered" with small additions of water. In 1974, Chemagro began adding lethicin to its Dylox 1.5 formulation to alleviate

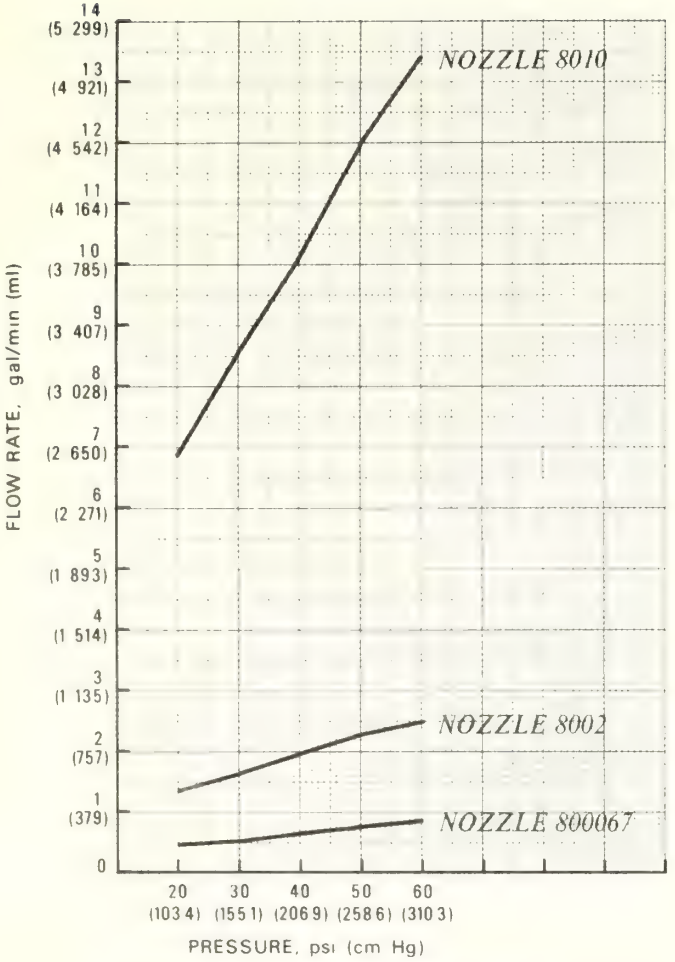

Figure 6.-- Flow rates of Dylox 1.5 at various pressures.

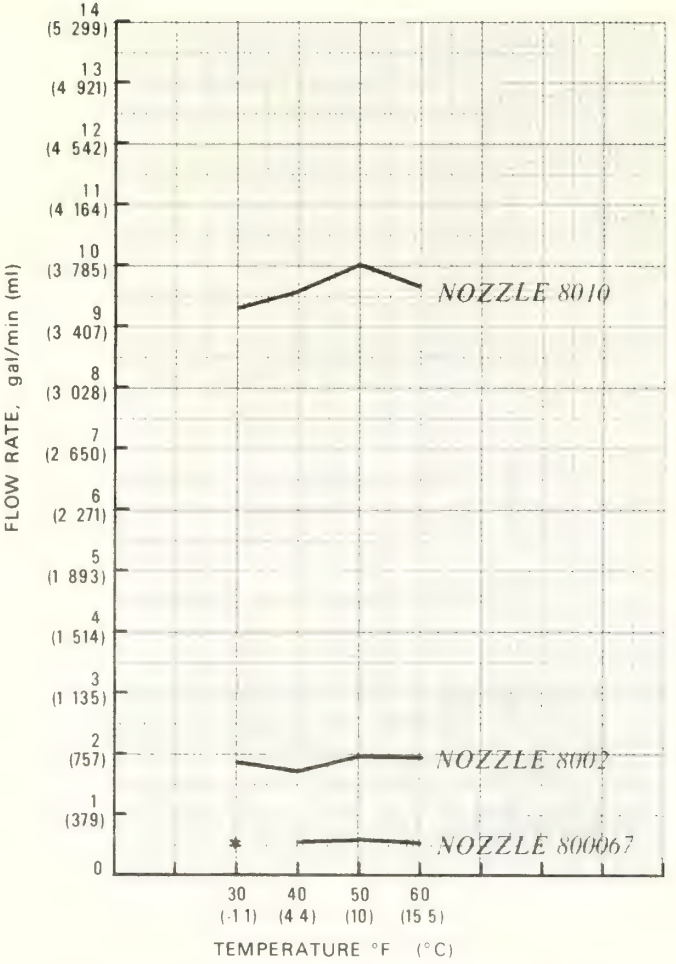

*Figure 7.--Flow rates of Dylox 1.5 at various temperatures. *Nozzle plugged.*

this problem. To determine if the problem still existed, we tested various water-Dylox mixtures with an 8002 nozzle at 40 psi (206.9 cm Hg). Table 2 shows a small change in flow rate at 4 percent water content and a large change at 6 percent (percentage by volume).

Table 2--*Change in flow rate of Dylox 1.5 caused by addition of water*

Percent of water in Dylox 1.5	Change in flow rate at 40 psi (206.9 cm Hg) and 55 °F (12.8 °C)
	Percent
1	3.38
2	5.46
4	7.85
6	11.11
8	12.87
10	14.23

Table 2 indicates that water-Dylox mixtures can be a problem in spray application. We found no indication of a "clabbering" reaction, however.

Pressure changes appeared to have a uniform effect on the flow rates. Figure 7 shows some not-so-regular flow rates. For example, the flow rate shown at 50 °F (10 °C) for the 8010 nozzle is 1.002 gal/min (3 793 ml/min), the mean flow rate for the 3 test minutes. The standard error is 43 ml, a variation of 1.13 percent in the measurements, which is probably not excessive.

Orthene

Orthene handled well in the spray system (figs. 8 and 9). The changes in flow rates were reasonably uniform during pressure and temperature variation. Orthene dissolved easily in water and was readily flushed from the system, unless it had a large depression or cul-de-sac where deposition could occur. Some material settled and compacted when allowed to stand overnight (table 3). This material was moderately difficult to resuspend.

Table 3--*Settling measurements of Orthene 75S (250-ml samples)*

Concentration	Settling time			
	24 hours	48 hours	6 days	12 days
	Milliliters			
1/2 lb ai/gal (0.06 kg/liter)	8	8	8	8
1 lb ai/gal (0.119 kg/liter)	13	12	13	13
2 lb ai/gal (0.238 kg/liter)	30	28	26	26

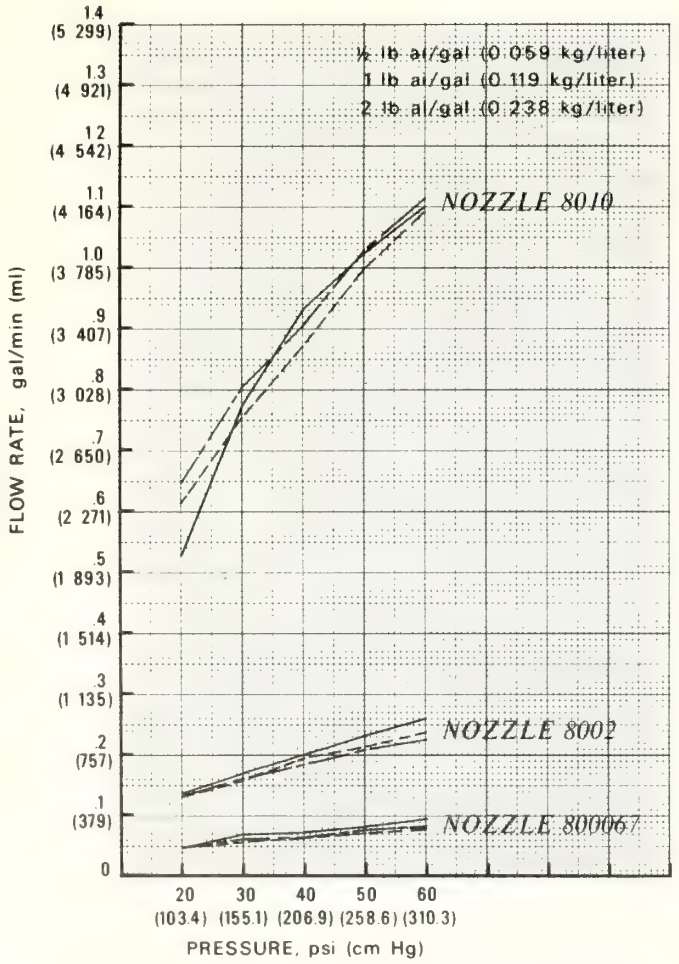

Figure 8.--Flow rates of Orthene 75S at various pressures.

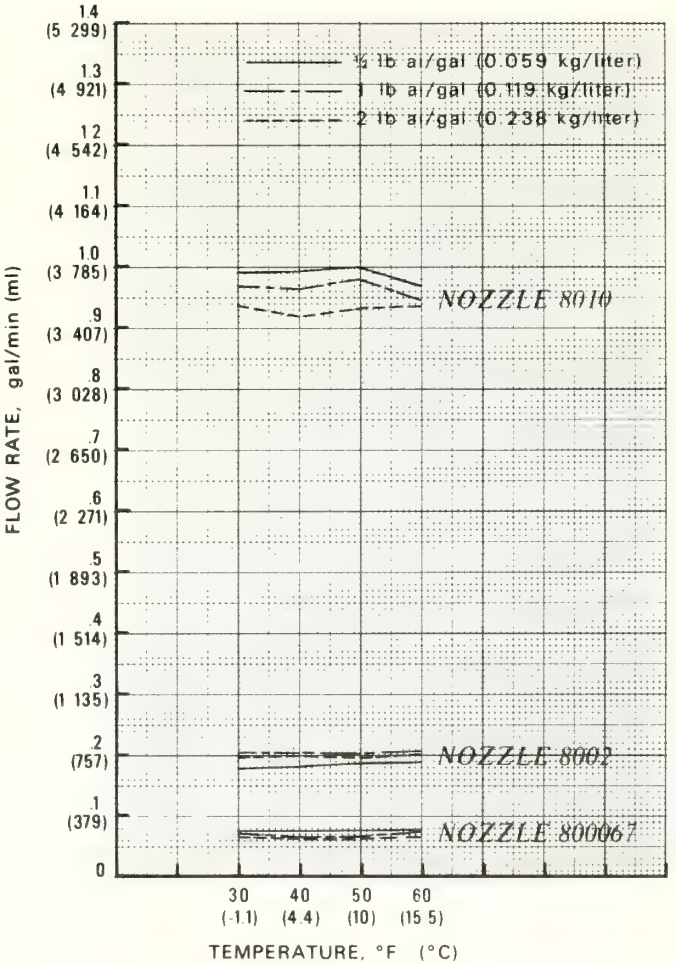

Figure 9.--Flow rates of Orthene 75S at various temperatures.

When resuspension began, the material broke off the floor of the container in irregularly shaped lumps, which could cause plugging under field conditions, but then suspended quickly. The more concentrated the formulation, the more difficult the resuspension becomes. If the resuspension was not uniform or complete, the lumps could cause severe problems in application.

Density and viscosity measurements of Orthene 75S were as follows:

Density

1/2 lb ai/gal (0.06 kg/liter) = 1.002 g/cu^3 or 8.35 lb/gal
1 lb ai/gal (0.119 kg/liter) = 1.017 g/cu^3 or 8.48 lb/gal
2 lb ai/gal (0.238 kg/liter) = 1.046 g/cu^3 or 8.72 lb/gal

Viscosity, at 20 °C

1/2 lb ai/gal (0.06 kg/liter) = 8 cps
1 lb ai/gal (0.119 kg/liter) = 8 cps
2 lb ai/gal (0.238 kg/liter) = 8 cps

Particulate foreign matter in the Orthene was a problem more serious than incomplete resuspension. Some plugging of screens and nozzles was observed. Orthene was mixed into filtered water in a cleaned container and filtered through a 100-mesh screen. Two kinds of particles were removed by the filter. One kind was dark and flakelike with diameters of 0.5 to 2 mm (0.0196-0.787 inches). The other was a plasticlike oily droplet, slightly gritty to the touch, approximately 1 mm (0.0392 inch) in diameter. The flake was heavier than water, the droplet lighter. The amount of residue was 0.27 g per 454 g of Orthene 75S (not 0.27 g per 454 g ai). The manufacturer indicates this problem has been corrected.

Sevin 4-Oil

When mixed with diesel (1:1), the Seven 4-oil performed fairly well in the spray system under various pressures and temperatures (figs. 10 and 11). The exception was at 40 °F (4.4 °C) with nozzle 8010. Since the other points are on a straight line, this discrepancy might have been caused by operator error.

At a dilution of 3:1 (3 parts Sevin:1 part diesel), the spray behavior became irregular. At 30 °F (-1.1 °C) (800067 nozzle), the nozzle plugged and the angle formed by the spray fan would not exceed 50° (80° is considered a full spray fan). The spray fan did not approach 80° until 60 °F (15.5 °C) was reached. When the 8010 nozzle was used, the tank pressure had to be increased to almost 80 psi (413.7 cm Hg) to obtain 40 psi (206.9 cm Hg) at the nozzle (see "Limitations of Design").

We tested pressure variation at 55 °F (12.8 °C) (800067 nozzle). The spray would not fan out properly (80°angle) until nozzle pressure was 50 psi (258.6 cm Hg) or above. When the 8010 nozzle was used, regulator pressures exceeded 80 psi (413.7 cm Hg) to achieve 50 psi (258.6 cm Hg) at the nozzle. We could not achieve 60 psi (310.3 cm Hg) nozzle pressure with the 8010 nozzle and three parts Sevin to one part diesel (see "Limitations of Design").

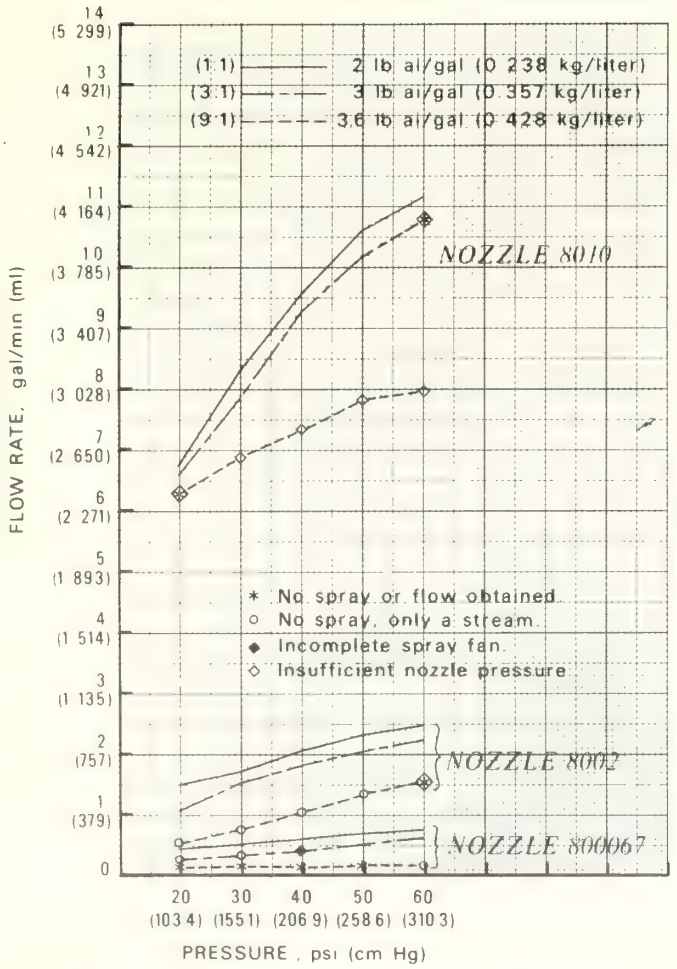

Figure 10.--Flow rates of Sevin 4-oil at various pressures.

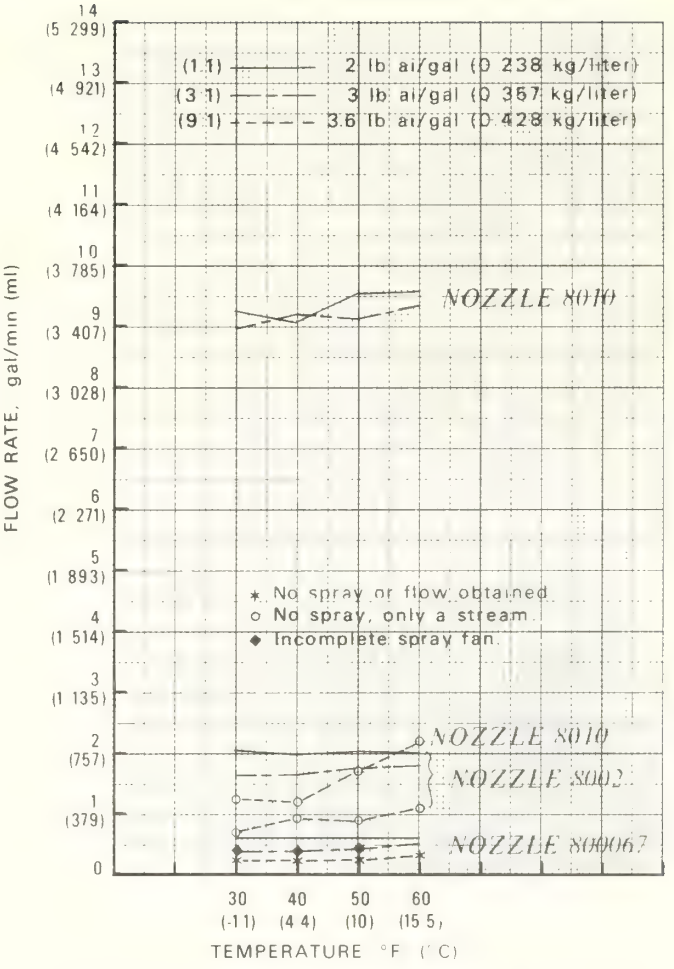

Figure 11.--Flow rates of Sevin 4-oil at various temperatures.

When nine parts of Sevin 4-oil was mixed with one part diesel (9.1), the formulation would not form a spray fan. The mixture left the nozzle as a stream of fluid, if at all (see "Limitations of Design").

Sevin 4-oil was not tested full strength. Settling, density and viscosity of 250-ml samples of Sevin 4-oil, as shipped (4 lb/gal or 0.476 kg/liter) were as follows:

Settling, 24 hours

2 lb/gal (0.238 kg/liter) = 5 ml clear fluid on top, 26 ml paste on bottom
3 lb/gal (0.357 kg/liter) = 4 ml clear on top, 17 ml paste on bottom
3.6 lb/gal (0.428 kg/liter) = 2 ml clear on top, no settled material

Density (mixed with fuel oil)

2 lb/gal (0.238 kg/liter) = 0.887 g/cu^3 or 7.395 lb/gal
3 lb/gal (0.357 kg/liter) = 1.01 g/cu^3 or 8.42 lb/gal
3.6 lb/gal (0.428 kg/liter) = 1.157 g/cu^3 or 9.645 9 lb/gal

Viscosity, at 20 °C

2 lb/gal (0.238 kg/liter) = 8.4 cps
3 lb/gal (0.357 kg/liter) = 44.5 cps
3.6 lb/gal (0.428 kg/liter) = 174 cps

No thick gummy precipitate settled out over a short period. The suspension appeared more dense toward the bottom. This suspended material did not exhibit more cohesive or adhesive properties, and it was easily stirred to a more uniform suspension. A small amount of clear fluid separated out at the top.

When allowed to stand for several hours, both mixtures with diesel (3:1 and 1:1) had a thick gummy paste, which was difficult to resuspend, at the bottom of the containers. The 9:1 dilution had no apparent settling problems.

This information indicated that, for other than immediate use, diesel fuel was incompatible as a carrier for Sevin 4-oil.

Water

The flow rates for water are presented for comparison (figs. 12 and 13). Figure 13 shows, partially, the effect of temperature on water density. The effect of temperature on flow rate was greatest at 40 °F (4.4 °C), but the differences may be masked by the temperature change of the water between output and measurement.

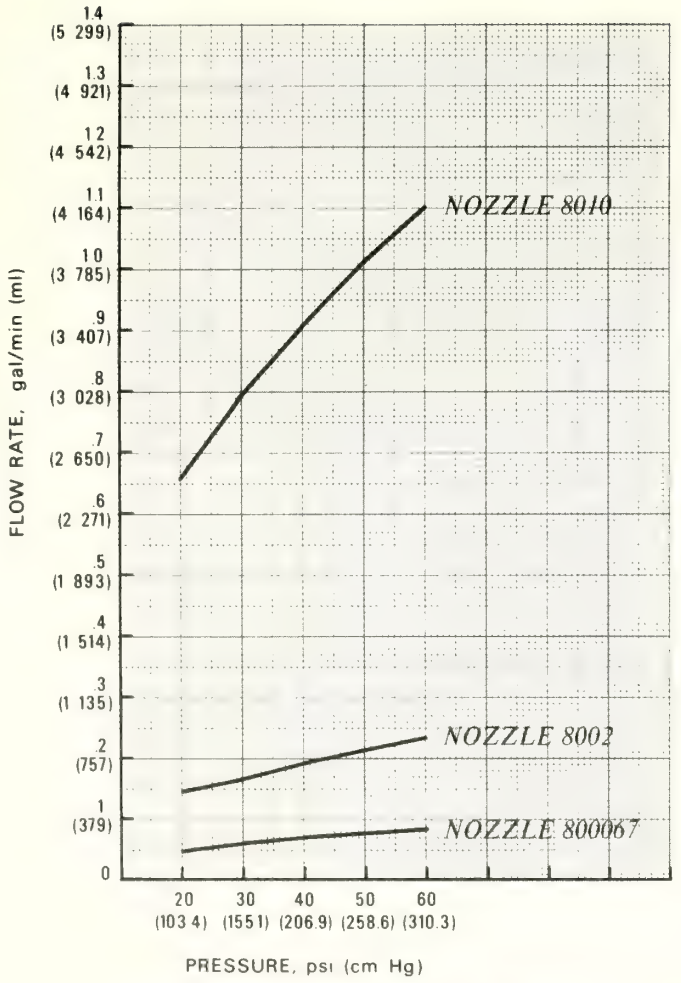

Figure 12.--Flow rates of water at various pressures.

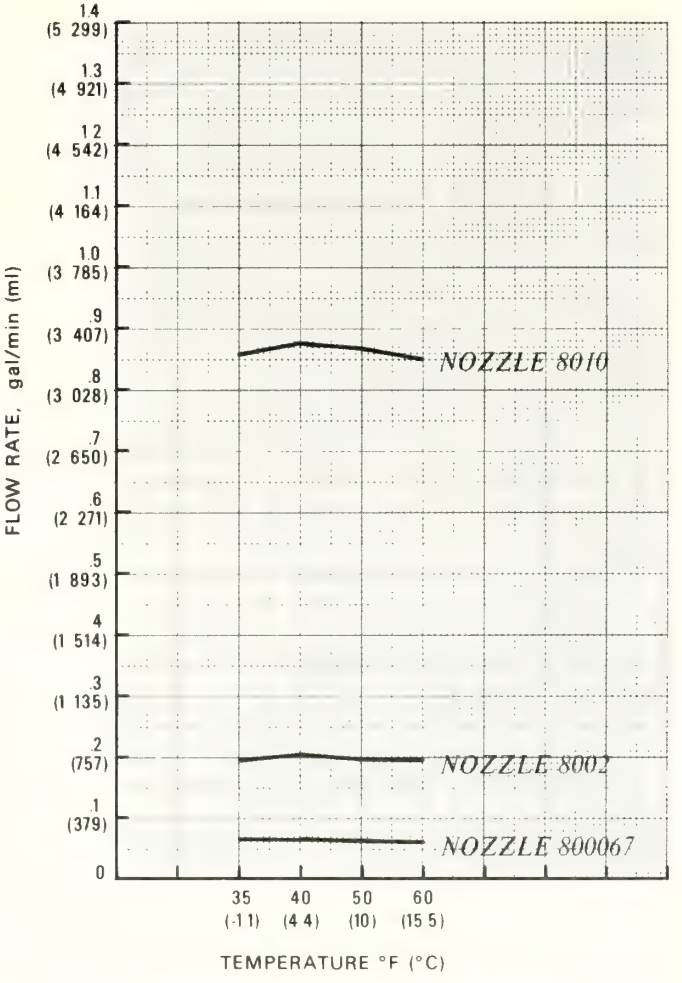

Figure 13.--Flow rates of water at various temperatures.

LIMITATIONS OF DESIGN

Several factors may have affected the results presented in this report. In addition, several test conditions should be altered in future tests.

First, we believe the diameter of the pipes and fittings from the pressure tank to the chamber were too small and caused difficulty with flow of the more viscous materials (Dylox 1.5 and Sevin 4-oil). This condition was shown by the large pressure drop from the tank to the nozzle, which may also have affected spray fan formation.

Second, a more appropriate way to measure flow rate would probably be to spray the material for 3-5 minutes, turning the spray on at the beginning and off at the end. This would eliminate some operator errors, such as reaction time, and would provide a more accurate estimate of flow rate. This would be especially important with the 8010 nozzles, since the larger orifice simply magnifies the error. This would, however, require larger volumes of formulations, chambers, and tanks, which would make the low temperature tests more difficult.

Third, there is some statistical validity for running these tests in a completely random order rather than sequentially. This was deemed impractical because of physical limitations, such as storage of all concentrations, temperature regulation of the chemical, frequency of cleaning test equipment, and additional time these precautions would require.

The system was designed to operate under pressure to eliminate or prevent, as much as possible, effects of other factors, such as mechanical friction and moving parts. Many aircraft spray systems use a centrifugal pump. The shearing action of a centrifugal pump may cause temperature increases of as much as 70 °F (37.2 °C), from 50 °F (11.7 °C) to 120 °F (48.9 °C) during application of a 50-gallon (189-liter) load (personal communication, J. Henderson, USDA/APHIS, Aircraft Operations, Hyattsville, Md., 1976). Similar temperature increases were also observed by Orchard, Forestry Sciences Laboratory, Corvallis, Oregon (personal communication, 1976). This was not known at the time of the test and would have greatly extended the range of the tests. This phenomenon should be investigated further in the laboratory and under field conditions, since it has the potential of altering the reliability, effectiveness, and properties of a given pesticide.

SUMMARY

This report has shown how pressure and temperature and concentration variables affect the flow rates of Dimilin, Dylox 1.5, Orthene 75S, and Sevin 4-oil. Some of their physical characteristics have been noted. Unfavorable results were due to settling and viscosity, but the limits of the facilities used in developing and testing the chemicals are recognized as having some effect.

We hope that these figures will be useful to other applicators and that they will encourage companies and research organizations to establish flow rates for other systems and chemical concentrations.

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife -- if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

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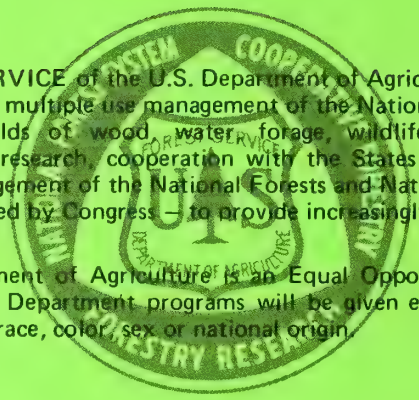

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USDA FOREST SERVICE RESEARCH NOTE

13.79 · PNW-301

PNW-301

August 1977

RESPONSE OF PONDEROSA PINE 8 YEARS AFTER FERTILIZATION

by

P. H. Cochran, *Principal Research Soil Scientist*

GOVT. DOCUMENTS DEPOSITORY ITEM

OCT 27 1977

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Abstract

Diameter and volume growth of individual ponderosa pine trees in thinned stands continues to respond to fertilizer 8 years after application in three of four study areas. Height growth is not responding to fertilization. Removal of bitterbrush in one study area decreased volume growth in the seventh and eighth growing seasons. Apparently brush removal stimulated fescue growth, increasing water and nutrient competition.

KEYWORDS: Fertilizer response (forest tree), fertilization (forest), increment (volume), volume increment, increment (diameter), diameter increment, thinning (tree), ponderosa pine, *Pinus ponderosa*, bitterbrush, brush control, growing season.

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Metric Conversion Factors

1 pound/acre	= 1.121 kilograms/hectare
1 acre	= 0.405 hectare
1 foot	= 0.3048 meter
1 inch	= 2.54 centimeters
1 square foot	= 0.092903 square meter
1 cubic foot	= 0.028317 cubic meter
1 mile	= 1.61 kilometers

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

Introduction

Response of individual ponderosa pine (*Pinus ponderosa*) trees to fertilization during the first four growing seasons after application was reported in an earlier note (Cochran 1973). As then outlined, 1/10-acre areas around dominant or codominant sample trees in thinned stands were fertilized. These stands are located in Sumpter Valley near Baker in northeastern Oregon and in central Oregon on the Fort Rock Ranger District, the Pringle Falls Experimental Forest, and 5 miles west of the Experimental Forest along Road 1808. The three central Oregon locations were chosen to represent areas differing in effective moisture. The Fort Rock and Road 1808 locations were thought to be the driest and wettest respectively.

In three of these four areas, 24 sample trees were selected so treatments could be replicated eight times. Treatments equivalent to 0, 200, and 400 pounds of nitrogen (N) per acre in the form of urea were used in Sumpter Valley. In addition to the control, the two levels of fertilizer application per acre in central Oregon were: (1) 200 lbs N, 100 lbs phosphorus (P), 30 lbs sulfur (S) and 1.88 lbs boron (B) and; (2) 400 lbs N, 200 lbs P, 60 lbs S, and 3.75 lbs B.

In the Fort Rock area 48 sample trees were selected so a shrub vegetation removal treatment for the 1/10-acre area could be superimposed on the fertilizer treatments used in the other two central Oregon areas. The experimental design is a randomized complete block. In the Sumpter Valley area blocks were chosen so that trees in each block were on the same slope and aspect and were the same distance from an abandoned irrigation canal. Blocks in the central Oregon areas were assigned on the basis of similar tree diameters. Some test tree and stand parameters established at the beginning of the study of the four areas are present in table 1.

During the first 4 years after application, fertilization increased height growth significantly at the Sumpter Valley and Road 1808 locations;

Table 1--*Some test tree and stand parameters at the beginning of the study*

Location	Mean starting values				Stand spacing	Stand age
	Diameter[1/]	Height	Basal area	Volume		
	Inches	Feet	Feet^2	Feet^3	Feet	Years
Sumpter Valley	10.0	51	0.556	9.66	15 x 15	64
Pringle Falls	10.2	52	.591	11.02	14 x 14	78
Road 1808	14.6	65	1.258	31.43	12 x 12	68
Fort Rock	12.2	47	.836	13.25	variable[2/]	variable[3/]

[1/] This diameter is the actual mean diameter of the test tree and not the diameter equivalent to the average basal area.

[2/] 10 x 10 feet to very open.

[3/] Stand consists of residual trees left after railroad logging in the 1920's and reproduction immediately after.

but there was no significant difference between the two levels of fertilization. The effect of fertilization on height growth tended toward significance in the other two areas, and results may have been confounded with top damage. Tree diameter and basal area growth were increased by fertilization in all the areas, but there was no difference among levels of application. Volume growth was also increased significantly by fertilization except in the Fort Rock area where the effect of fertilization was almost, but not quite, significant at the 5-percent level. This study was continued beyond the first 4-year period after fertilization to obtain more information about duration of response.

Current Methods of Study

Fire destroyed the Silviculture Laboratory and the records for this study 2 years after measurements were taken for the previous report (Cochran 1973). Fortunately, a copy of the study plan and increment core measurements taken at the end of the first 4-year period were available from Pacific Northwest Forest and Range Experiment Station headquarters. Original diameters and heights and those for the end of the 4-year period were lost. Records of increment borings for each tree from all study areas, showing the diameter growth 4 years previous to treatment and 4 years after treatment, were retrieved. Trees were measured with optical dendrometers following the sixth and eighth growing seasons after treatment. Increment borings were again made on two opposite sides of every tree to determine diameter growth during the 4-year period previous to treatment and the first and second 4-year periods after treatment. The increment measurements were then compared with those previously taken and used to identify the treatments given each tree.

Because diameter growth was significantly increased by fertilization during the 4 years after initiation of the study, identification of the control trees for each replication in each area was certain. Separation of the test trees for the two levels of fertilization was questionable for some of the replications. Therefore, analyses of possible differences in responses between levels of fertilization were not attempted. Identification of the shrub removal treatments in the Fort Rock stand was certain because the outline of the 1/10-acre area was clearly visible and no shrubs had reinvaded the areas.

Height and volume growth for the seventh and eighth growing seasons after treatment were obtained from dendrometer readings subjected to the STX program (Grosenbaugh 1964). This program incorporated a modification of Brickell's equation (Brickell 1970) for diameter outside bark to diameter inside bark conversion developed by Cochran (1976). Diameter growth was determined from the increment borings.

Diameter and volume growth were subjected to analysis of covariance using diameter growth for 4 years previous to treatment as the covariate. Height growth was subjected to a standard analysis of variance.

Results and Discussion

Height growth during the seventh and eighth growing seasons after initiation of the study was not increased significantly (at the 5-percent

level of probability) by fertilization or shrub removal (table 2). A significant increase in height growth at the Pringle Falls location would have occurred if the probability level was increased to 8 percent.

Table 2--*Average annual height growth for the seventh and eighth growing seasons*

Location	Treatments		F values[1/]
	Control	Fertilized	Control vs. fertilized
	- - - - Feet - - - -		
Sumpter Valley	0.7	0.9	1.1575
Pringle Falls	.6	.85	3.8039
Road 1808	.7	.6	.2588
Fort Rock	.6	.6	.0040
	Shrubs present	Shrubs removed	Shrubs present vs. Shrubs removed
Fort Rock	.65	.6	.1121

[1/] F values have 1 and 14 degrees of freedom except for the Fort Rock location where both F values have 1 and 35 degrees of freedom.

Diameter growth during the second 4 years after treatment was significantly increased by fertilization except in the Road 1808 stand (table 3). The increase in diameter growth due to fertilization would have been significant at the Road 1808 location if the probability level was raised to 11 percent. Shrub removal did not significantly influence diameter growth in the Fort Rock area.

Volume growth during the seventh and eighth growing seasons after treatment was increased significantly (at the 5-percent level of probability) by fertilization except in the Road 1808 area (table 4). Even though in the Road 1808 area large differences in adjusted means for volume growth occurred, the probability level would have had to be 13 percent to be significant. This is due to large variation among replicates within treatments. The dense Road 1808 stand has more volume on each 1/10 acre and some of the test trees are codominants with other trees on the 1/10 acre. The competition of the other trees with the test tree for nutrients and water may be greater and more variable than in the other study areas.

Removal of shrubs (all shrubs were bitterbrush (*Purshia tridentata*)) on the Fort Rock area significantly decreased volume growth during the seventh and eighth growing seasons, but no significant interactions of shrub removal and fertilization occurred. A decrease in volume growth due to shrub removal is difficult to explain and seems contrary to other published work. Barrett (1970) found that removal of all understory vegetation (shrubs plus grasses and sedge) increased growth of thinned pine in a study on the Pringle Falls

Table 3--*Average annual diameter growth for the fifth, sixth, seventh, and eighth growing seasons after treatment. Values calculated using adjusted means obtained from covariant analysis*

Location	Treatments		F values[1/]
	Control	Fertilized	Control vs. fertilized
	- - - Inches - - -		
Sumpter Valley	0.16	0.20	10.6619[2/]
Pringle Falls	.16	.23	18.6377[2/]
Road 1808	.16	.19	3.0100
Fort Rock	.13	.18	33.0581[2/]
	Shrubs present	Shrubs removed	Shrubs present vs. Shrubs removed
Fort Rock	.17	.16	.0058

[1/] F values have 1 and 13 degrees of freedom except for the Fort Rock location where both F values have 1 and 34 degrees of freedom.

[2/] Indicates significance at the 5-percent level of probability.

Table 4--*Average annual volume growth for the seventh and eighth growing seasons after treatment. Values calculated using adjusted means obtained from covariant analysis*

Location	Treatments		F values[1/]
	Control	Fertilized	Control vs. fertilized
	- - - Feet^3 - - -		
Sumpter Valley	0.47	0.83	9.5161[2/]
Pringle Falls	1.22	2.00	5.3055[2/]
Road 1808	1.33	2.19	2.7515
Fort Rock	1.02	1.43	4.5419[2/]
	Shrubs present	Shrubs removed	Shrubs present vs. Shrubs removed
Fort Rock	1.50	1.09	5.8442[2/]

[1/] F values have 1 and 13 degrees of freedom except for the Fort Rock location where both F values have 1 and 34 degrees of freedom.

[2/] Indicates significance at the 5-percent level of probability.

Experimental Forest. Gordon (1962) found that understory vegetation adversely affected growth of ponderosa and Jeffrey pine poles. He further concluded that perennial grass had a greater effect than broad leaved plants. Although production was not measured in the Fort Rock area, it appears that removal of the bitterbrush stimulated the grass production, particularly fescue (*Festuca idahoensis*). An increase in the overall competitive affect may have occurred.

Summary and Conclusions

Diameter growth as well as the volume growth of trees in thinned stands are still responding to fertilization 8 years after treatment in three of four study areas. Height growth is no longer responding to fertilization in the Sumpter Valley and Road 1808 areas where significant differences occurred during the first 4 years after treatment.

Shrub removal alone in the presence of fescue did not reduce competition to overstory but produced a situation where fescue apparently was competitive to tree growth.

This study shows that foresters can expect significant responses, visibly noticeable on increment cores, to fertilization in thinned stands of pines which will last at least 4 to 8 years.

Further work is underway to correlate response with kinds and amounts of fertilizer and various kinds of soils in different plant communities. Other work in preparation for publication suggests that P, S, and B in combination with N do not stimulate volume growth in the field. For land managers wishing to fertilize thinned ponderosa pine stands now, the tentative recommendation of 200 pounds of elemental nitrogen per acre in the form of urea is offered.

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GPO 999-073

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USDA FOREST SERVICE RESEARCH NOTE

13.79 : PNW-302

PNW-302 *October 1977*

FIELD TEST OF ACEPHATE AGAINST TWO DOUGLAS-FIR CHRISTMAS TREE PESTS

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by

Russel G. Mitchell, *Principal Insect Ecologist*

and

John Neisess, *Chemist*

Abstract

When acephate was applied to Douglas-fir Christmas trees before and after bud burst, it significantly reduced the Douglas-fir needle midge *(Contarinia pseudotsugae)* population. The same treatments did not significantly reduce the summer generation of Cooley spruce gall aphid *(Adelges cooleyi)* population but caused increased populations in the winter generation. Symptoms of phytotoxicity occurred on trees treated after bud burst.

KEYWORDS: Insecticides (-forest pests, needle midge, *Contarinia pseudotsugae*, Cooley spruce gall aphid, *Adelges cooleyi*, Christmas tree crops, Douglas-fir, *Pseudotsuga menziesii*, acephate, phytotoxic effects (pesticide).

EST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

Two common insect pests of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) Christmas trees in western Oregon and Washington are the Douglas-fir needle midge (*Contarinia pseudotsugae* Condrashoff)[1/] and the Cooley spruce gall aphid (*Adelges cooleyi* (Gillette)). Neither insect kills the tree, but both damage new needles and thus affect tree appearance and value.

C. pseudotsugae is the more serious of the two pests. The adult emerges from the soil in the spring and lays eggs on expanding buds and needles. Newly hatched larvae mine into the new needles, and yellow or purple galls form at the point of attack. About November, the galled needles usually turn brown and fall from the tree. Defoliation in some years can be severe enough to make nearly every tree in a plantation unmerchantable (Condrashoff 1962).

A. cooleyi is normally the less damaging pest but can cause a large number of unsightly trees. Injury stems from emerging nymphs of the overwintering generation which feed on new growth. The most severe damage occurs on the young, tender needles just out of the buds. These needles develop severe crooks and chlorotic blotches at the feeding sites (Crooke 1960). Heavy attacks can also reduce twig growth and cause premature needle fall.

Growers have recently been reducing damage to new growth by applying the insecticide endosulfan (Nagel 1968; Saunders and Barstow 1970). One application at the start of bud burst has been effective against both pests, but the high cost and safety hazards of the material make alternative insecticides desirable.

This paper describes a 1976 field experiment in Oregon which tested the efficacy of the insecticide acephate against these two Christmas tree pests. Acephate was selected because it was likely to be safer and cheaper to apply than endosulfan, and because the reported systemic qualities seemed applicable to the biology of the two pests we wanted to control.

[1/] *Contarinia pseudotsugae* Condrashoff is the principal member of a three-species complex. The other two species, *C. constricta* Condrashoff, and *C. cunicular* Condrashoff, are unimportant in western Oregon and Washington.

Materials and Methods

The general framework of the test was to determine if acephate would contol midges and aphids when applied to individual trees at three doses both before and after bud burst. The test was conducted on a 2-acre (.8-ha) Christmas tree plantation 15 miles (24 km) south of Corvallis, Oregon. Moderate populations of both the needle midge and the gall aphid were observed there in 1975 and 1976. All trees were sheared Douglas-fir grown in rows and spaced at 6-foot (1.8-m) intervals. The trees were 6 years old and ranged in height from 4 to 7 feet (1.2 to 2.1 m).

The experimental design was two spray periods and 4 treatments per spray period. Times and treatments were then randomly assigned to 240 randomly selected trees--120 trees per spray period and 30 trees per treatment. The first spray period was on May 3, just before most of the trees had burst buds. The second spray period was on May 11, when about 60 percent of the trees had burst buds. A scheduled third spray at 100 percent bud burst was cancelled because of phytotoxicity in the second treatment.

Thirty unsprayed trees served as a check in each spray period. Each of the remaining 90 trees was treated with 1 pint (473 ml) of insecticide solution delivered through a nozzle held directly above the treated tree. The amount of acephate (Orthene 75 S) in 1 gal. (3 785 ml) of water of the 3 insecticide treatments was: Low - 0.05 lb AI (22.5 g); Medium - 0.1 lb AI (45.5 g); and High - 0.2 lb AI (92.7 g). Spray drift to adjacent trees was avoided by enclosing the treated trees at the time of treatment within a portable, plastic-covered screen (fig. 1).

Figure 1--Post bud burst treatment of Douglas-fir Christmas tree with acephate. Portable, plastic-covered screen protected other trees from contamination.

It was partly cloudy on the day of the first spray period, and the temperature was 68°F (20°C). Heavy rain showers occurred in the area about 40 hours after the spray was applied. Temperature on the day of the second spray period was 72°F (22°C), and the sky was clear. The first rain was recorded 9 days after spraying.

Treatment effectiveness was evaluated by comparing pest population densities on unsprayed check trees with those on treated trees. For *C. pseudotsugae*, the number of galls was counted in late July on six 5-in. (12.7-cm) twigs clipped from the midcrown of each tree. The sample procedure was the same for *A. cooleyi* except that the aphids were counted in early July on four twigs. The average number of needles in each sample unit was about 700 for the midge and 500 for the aphid. A larger sample unit was selected for midges because it appeared the within-tree sample variation would be greater.

In the spring of 1977, a quick classification system was devised to reevaluate *A. cooleyi* populations on plot trees. The classification established 5 population categories. Guidelines used in the classification were: 1 = no aphids or only occasional aphids, 2 = 1 aphid per 100 needles, 3 = 10 to 50 aphids per 100 needles, 4 = 1 aphid per needle, and 5 = 5 or more aphids per needle. Populations falling between guideline figures were placed in the category to which they appeared closest.

Data were statistically analyzed according to standard procedures for an experiment with a completely randomized factorial design. With one exception, the established probability level for statistical significance was $P \leq 0.01$. With the midge, it was necessary to use logarithmic transformations on the data to equalize variances within treatments.

Results

Acephate reduced Douglas-fir needle midge populations when applied either before or after bud burst (table 1.) In both periods, there was a significant decrease in midge populations with increasing insecticide dose. When spray dates were compared, the population reduction for the pre-bud burst treatment was significantly greater than for the treatment at 60 percent bud burst. Also, a test of interaction showed that the pre-bud burst treatment was progressively and significantly more effective with increasing dosage than the treatment at 60 percent bud burst.

Acephate was not effective against the spring generation of *A. cooleyi*. The data, summarized in table 2, suggest a trend toward population reduction; but differences were not statistically significant. When the winter generation was checked a year after treatment, it was found that the aphid population was significantly greater on treated trees than on untreaed trees (table 3). Also, the trees treated at 60 percent bud burst had a significantly ($P<0.05$) greater population than trees treated before bud burst.

Table 1--*Mean numbers of* C. pseudotsugae *per tree on acephate treated and check trees*

Spray period	Treatment dose				Mean[1/]
	Check	Low	Medium	High	
Pre-bud burst	75.113	0.163	0.007	0.006	0.153
Post-bud burst	96.351	.944	.444	.007	.738
Mean[1/]	85.030	.392	.057	.007	--

[1/] Means will not balance because they are based on untransformed mean logs.

Table 2--*Mean numbers of* A. cooleyi *per tree on check trees and trees treated with acephate (summer generation, 1976)*

Spray period	Treatment dose				Mean
	Check	Low	Medium	High	
Pre-bud burst	58.2	53.8	41.0	23.4	44.1
Post-bud burst	40.0	36.3	36.8	34.6	36.9
Mean	49.1	45.0	38.9	29.0	--

Table 3--*Mean population of* A. cooleyi *per tree based on classification of five population categories*[1/] *(winter generation, 1977)*

Spray period	Treatment dose				Mean
	Check	Low	Medium	High	
Pre-bud burst	1.53	2.63	2.70	2.33	2.30
Post-bud burst	1.53	2.97	3.20	2.50	2.55
Mean	1.53	2.80	2.95	2.41	--

[1/] 1 = No population, 2 = light population, 3 = medium population, 4 = heavy population, 5 = very heavy population.

A phytotoxic reaction was observed on trees that had flushed in the 60 percent bud burst treatment. New needles were burned at all three dosages. Damage was most severe at the high application rate, resulting in injury to 10-50 percent of the new needles. Damage was also conspicuous at the low dose, though less than 1 percent of the needles were affected.

Most damaged needles were on the tops of the new shoots and at the basal ends. Some needles turned completely red, but usually only the distal 1 to 2 cm faded. First signs of redness appeared about 7 days after spraying and the damage was most noticeable after about 1 month. By September, most of the burned needles had fallen from the trees.

A slight symptom of phytotoxicity was also observed associated with the treatment before bud burst. Trees treated with the high dose of acephate developed a distinct yellowing at the distal 2 to 3 mm of the needles. This condition was still apparent in March 1977.

Discussion

The key findings of this test were that acephate (1) controlled midges and (2) was effective as a systemic insecticide when applied before bud burst. The reason the treatment prior to bud burst was more effective than treatment at 60 percent bud burst appears related to the infestation characteristics of the midge. Aborted attacks were observed to be quite common in both treatments, suggesting that most control occurred as the larvae first began to bore into the needles. Insects surviving the second treatment appeared to be those that were already inside the needles, that is, those that attacked in the time interval between bud burst and treatment. Gall formation, which begins immediately after attack, appeared to inhibit translocation of the insecticide to the infestation site.

The inability of acephate to significantly reduce the summer generation of *A. cooleyi* was disappointing. Even more disappointing was the discovery that the treatment eventually lead to increased populations in the winter generation. Many of the treated trees had the heaviest *A. cooleyi* populations we had ever seen. Apparently, acephate is more toxic to the predators (*A. cooleyi* has no parasites) than it is to the prey. And because immature predators (mostly syrphids and anthocorids) are most abundant on infested trees just after bud burst, the treatment at 60 percent bud burst was more disruptive than the treatment before bud burst. Any future tests with acephate on Douglas-fir will need a check to determine if *A. cooleyi* populations are released by the spray. This problem could negate any expected benefits from acephate in controlling the midge population.

Conclusion

If acephate has potential value against the Douglas-fir needle midge, and if we are going to realize that value, we still need to clarify three points. First, we should determine if acephate can be effectively applied from the air, since many Christmas tree farms in the Pacific Northwest are too large for ground-spray operations. Second, to add flexibility to control programs, it should be established how early before bud burst acephate can effectively be applied. Last, because the lowest treatment rate in this test was 99.8 percent effective, it is likely that the minimum dose could be reduced even more.

The occurrence of phytotoxicity was interesting but of no practical consequence to Christmas tree growers. Most control efforts against the gall midge would likely occur before bud burst and probably at a lower insecticide concentration than was used in this test. A lower dose may also solve the problem of resurging aphid populations.

Acknowledgments

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ALASKA OREGON WASHINGTON
PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

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EFFECT OF WETTING MODE ON SHEAR STRENGTH OF TWO AGGREGATED SOILS [1/]

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by

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and

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ABSTRACT

High degrees of soil aggregation caused anomalously large angles of internal friction of 40°-42° for two cohesionless soils of the Oregon Coast Ranges. Soil aggregation and wetting by immersion during shear tests caused angles of internal friction of saturated soil to be atypically 9.5°-11° smaller than angles of internal friction of dry soil. Also, amounts of water-stable aggregates were 23 to 35 percent less after saturation by immersion of soil samples than after saturation by tension wetting. This suggests that the mode of wetting a sample may influence the apparent angle of internal friction for such soils.

KEYWORDS: Soil testing, soil stability.

[1/] A portion of this work was financed by a grant from the Water Resources Research Institute, Oregon State University, Corvallis.

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INTRODUCTION

In soil stability problems, knowledge of soil shear strength parameters is required. Determination of the proper values of the strength parameters to use in a stability analysis can be the most difficult task in soil engineering. In tests for shear characteristics, external forces are applied to the soil test specimen in such a way as to cause adjoining parts of the specimen to slide (shear) relative to each other. The stress developed within the soil, in opposition to shearing, is termed shear resistance. The shear resistance developed at failure is the shear strength of the soil. The ratio of shear strength to shear stress along a critical sliding surface within a soil mass is the factor of safety (F) of the soil mass. The soil mass will fail or is about to fail if F is ≤ 1.0.

Soil shear strength is generally considered to be a function of apparent cohesion, intergranular friction, and effective normal stress. This relationship, called Coulomb's Law, is given by:

$$S = c' + \sigma' \tan \phi' \quad ;$$

where,

S = shear strength
c' = cohesive strength
σ' = effective stress normal to the shear surface
ϕ' = angle of internal friction.

Shear parameters are not physical constants; they vary with stress history, soil structure, degree of disturbance, degree of packing and density, and water content of the soil. For example, clay soils are normally strong when dry but may be very weak when wet. Therefore, in soil strength tests, the condition of the test specimen must represent as nearly as possible the appropriate field condition of the soil at the time of critical stability.

The test method may also affect shear strength values. If drainage from a saturated soil specimen during a shear test is prevented, pressure develops in porewater, and strength is reduced. This reduction occurs because shear strength is proportional to the effective pressure between the soil particles, which, in turn, equals total pressure minus porewater pressure. Thus, for constant total pressure, increased porewater pressure decreases strength (Terzaghi and Peck 1967).

Shear strength tests have not been completely standardized because considerable freedom in testing procedures is necessary for properly testing soil samples to determine their behavior under field stress conditions. All shear strength test methods, however, do recognize the importance of adequately defining the drainage and consolidation conditions during the test.

The purpose of this study was to determine if the stability of soil aggregates and the method of saturating a test sample could influence the strength parameter values for two cohesionless soils--soils which rely almost entirely on intergranular friction for strength and are usually granular and nonplastic.

SOIL TESTING

Sample of Klickitat and Bohannon soils from four sites in the central Coast Ranges of Oregon were tested. Klickitat soils are derived from intrusive igneous rocks; the Bohannon soils are derived from arkosic sandstone. Together, these two soils occupy over 90 percent of the area having cohesionless soils in the central Coast Ranges (Corliss 1973). Both are commonly found on the steepest and most sensitive slopes.

Soils were tested in the laboratory to determine their strength characteristics and the stability of their aggregates. Because Atterberg Limits tests and preliminary triaxial shear testing indicated soils were cohesionless, we used the triaxial test procedure described by Lambe (1951, p. 98-109) to determine angles of internal friction (Φ') of air-dried samples. Since suitably undisturbed soil samples could not be obtained because of the friable, cohesionless nature of the soils, samples were reconstructed to approximate field densities. No roots or other large pieces of organic matter were included in the reconstructed soils. We used a modification of Kemper's (1965) procedure to determine aggregate stabilities of soils wetted under tension and by direct immersion. Further details of laboratory tests are given in Yee (1975).

RESULTS AND DISCUSSION

Shear Tests

Results of shear tests are summarized in table 1. Values of angles of internal friction (Φ') for dry soil averaged about 41°, much higher than expected for such loose, porous soils. For example, dry, loose sands and silty sands tested under effective stresses (σ') of 5 kg/cm^2[3/] commonly exhibit values of 27°-33° (Terzaghi and Peck 1967). We could find no comparable cases in the literature where such loose, highly aggregated soils were tested.

3/ Here we follow the common engineering practice of expressing mechanical stress in units of force per unit area. Mechanical stress is correctly expressed in units of mass per distance x time squared (M/LT^2) or in newtons per square meter. One kg/cm^2 equals 9.807 x 10^4 newtons/m^2 which equals 1 pascal, the standard international unit of stress.

Table 1--*Results of triaxial shear testing of dry and saturated Klickitat and Bohannon soils*[1/]

Soil series	Soil condition	Initial porosity	Angle of internal friction (Φ')	Decrease	"t" statistic	Strain at failure	"t" statistic
		Percent		Percent		Percent	
Klickitat	Dry	61.4	41.49°	23	10.85*	5.7	10.82*
	Saturated	61.3	32.00°			11.0	
Bohannon	Dry	60.6	40.46°	28	14.63*	5.2	8.01*
	Saturated	60.0	29.31°			10.8	

*Statistically significant at the 0.1-percent level of probability.

[1/] Values for porosity, internal friction (Φ), and strain are means of five samples.

The anomalously large angles of internal friction are attributed to the high degree of aggregation found in these soils. Because the stability of the aggregates of both soils was sufficient to resist substantial dispersion techniques during particle-size analyses (Lambe 1951, p. 29-42), particles in the soil framework were assumed to be stable enough to function as individual primary particles, at least for the range of effective stresses under which testing took place. These large, composite particles tend to increase the grain interlocking and make the framework more resistant to stress. Large, composite particles functioning as primary units tend to have greater angularity, rougher surfaces, and larger effective sizes than would individual particles. This is especially true for more weathered soils which have more rounded and platelike individual particles. Therefore, the high degree of aggregation, coupled with the high aggregate stability, apparently produced the unusually high Φ' values in these soils. Shear of these soils may involve considerable breaking of the grains as well as rolling and sliding.

From Coulomb's equation, it is apparent that the higher Φ' values for both soils should produce greater shear strength for the same effective stress. For soils on steep slopes, high Φ' values have important benefits for maintaining slope stability.

The large differences in Φ' values, 9.5°-11° less in saturated soils than in dry soils, are also anomalous (table 1). Reductions of this magnitude are atypical compared with those of other studies of the effect of water on the angle of internal friction of cohesionless soils. According to Terzaghi and Peck (1967) and others, there should not be a reduction in Φ' because of moisture in a cohesionless soil. Also, no significant change in the strain at failure should occur. In this study, the large differences in angles of internal friction between dry and saturated soils are attributed to the high degree of aggregation and the stability of aggregates.

A major factor affecting the stability of wetted aggregates is the mode by which they are wetted. One mode, direct immersion of a dry soil in water at atmospheric pressure, causes the greatest disruption of aggregates (Kemper and Chepil 1965). Air is trapped within the aggregate by such rapid wetting, and the air is compressed by the advancing water film. This air bursts the aggregate's structure when it is sufficiently weakened by hydrating (Emerson and Grundy 1954). These miniature explosions can disintegrate aggregates.

The other possible mode of water entry is wetting under tension, the normal mode of wetting for subsurface soils (Kemper and Chepil 1965). The slower wetting under tension results in very little entrapment of air and hence less disruption of the aggregates in the main body of soil (Kemper 1965).

The influence of the wetting mode on soil aggregates is shown in table 2. The effect of direct wetting was extremely detrimental to the aggregates, and severe reductions in aggregate content occurred in both soils. Paired "t" tests (Snedecor and Cochran 1956) showed reductions are statistically significant at the 0.1-percent level of probability.

Table 2--*Aggregate stability of Klickitat and Bohannon soils saturated under tension and by direct immersion*

Soil series	Soil pit	Stable Aggregates		Decrease	Number of sample pairs	"t" statistic
		After tension wetting	After direct immersion			
		----------Percent----------				
Klickitat	A	84.2	62.7	26	6	8.73*
	B	83.8	64.3	23	8	10.47*
	A + B	84.0	63.6	24	--	--
Bohannon	C	88.6	63.1	29	14	11.96*
	D	86.3	56.1	35	6	7.27*
	C + D	87.9	61.0	31	--	--

*Statistically significant at the 0.1-percent level of probability.

The influence of the wetting mode on aggregates of both soils possibly explains the results of the shear tests. During the saturated shear tests, samples were saturated under only a slight vacuum in order to avoid sample consolidation, a potential problem with the low sample densities used. Consequently, the samples were saturated by direct wetting, and many soil aggregates were destroyed; others were weakened. Composite particles which had previously acted as single, primary units with larger effective sizes, greater angularity, and increased surface roughness, were reduced to smaller, more platelike and rounded particles. This most likely decreased the intergranular friction angle of both soils.

Shearing resistance caused by interlocking of grains was most likely also reduced. Such interlocking accounts for a substantial portion of the total shearing resistance of loose, cohesionless soils (Chen 1948) and requires that some grains be lifted and rolled over others as sliding occurs along the failure planes. Since the motion of individual particles--in this case, composite aggregated particles--has a component normal to the plane of failure, a considerable amount of work required to produce failure must be used in overcoming the resistance which the normal force offers to this motion. If a substantial number of primary particles are reduced to their smaller individual components, the amount of interlocking resistance would probably be reduced because adjacent grains would have a smaller distance to be lifted. The same is true for aggregates not completely destroyed but merely weakened. Weakening of intra-aggregate bonds would allow failure to occur within as well as between aggregates. Again, the amount of work necessary to overcome interlocking would be reduced. Composite particles whose bonds were merely weakened also experienced greater distortions before sliding commenced and produced the greater failure strains observed during testing of saturated soils (table 1).

The 23-percent decrease in the average angle of internal friction for the Klickitat soil and 28-percent decrease for the Bohannon soil (table 1) were accompanied by 24- and 31-percent decreases, respectively, in the average aggregate stability (table 2). Whether or not samples saturated under conditions of tension wetting and subjected to shear would yield Φ' values closer to those under dry conditions is unknown. If we consider the greater percentage of aggregates remaining intact under tension wetting for both soils, the Φ' value for a sample wetted under tension might be closer to the Φ' value of a dry sample than to the Φ' value of a sample wetted by immersion.

Application of Results

Because mode of wetting may greatly alter soil strength, the engineer conducting shear tests must monitor the drainage during shear and the wetting mode used in saturating soil samples. If he believes the angle of internal friction for cohesionless soils is not greatly affected by water, then he may test such a soil in the dry state because such testing is simpler and faster. If the soil is aggregated, however, he would obtain a higher Φ' value than he would if he tested a soil in a saturated state. In either case, the Φ' value could be erroneous and nonrepresentative of what would occur under field conditions of wetting.

Using the Φ' value for a dry soil may be adequate for analyzing dry soils and tension-wetted soils but might be hazardous for analyzing such soils on a slope that could be subjected to direct wetting. For example, consider a situation which could arise when water from a newly constructed ditch-culvert drainage system empties onto soil below a forest road. A system of ditches and cross-draining culverts is the most common means of controlling runoff from forest roads in the Pacific Northwest, and culverts empty into

linear depressions, onto sidehill slopes, or into established watercourses. Some shallow soil is usually present in most linear depressions on steep slopes. The soil in the depression may have carried saturated subsurface flow, but this saturation occurred under tension. Now, with the road present, the new culvert periodically may deposit varying quantities of water into the depression and subject the soil profile below the culvert to direct wetting. The flow of water may not be enough to wash away the soil nor to cause an increase in porewater pressure sufficient to initiate sliding, but some soil aggregates may be destroyed or weakened.

Lowering the angle of internal friction in this portion of the soil could create a small weak point along the potential failure plane. The soil, however, may not fail at this time. Although some of the deaggregated soil particles may even reaggregate over time (Lutz and Chandler 1961), usually neither the total number of aggregates nor the overall degree of aggregation is as great as it was initially. As subsequent inundations occur, the zone of aggregate destruction may increase or spread and intensify in areas previously deaggregated. At some future date, perhaps after many years, the factor of safety (F) is reduced to the point where failure occurs. Figure 1 illustrates the process described. Areas 1, 2, and 3 reflect the hypothesized portions of the soil profile affected by inundation events and, hence, have had their angle of internal friction (Φ') lowered. At some event n, the reduction in F to or below 1.0 causes the slope to fail. This may explain in part why some road-associated slope failures occur during moderate rainfall rather than heavy rainfall.

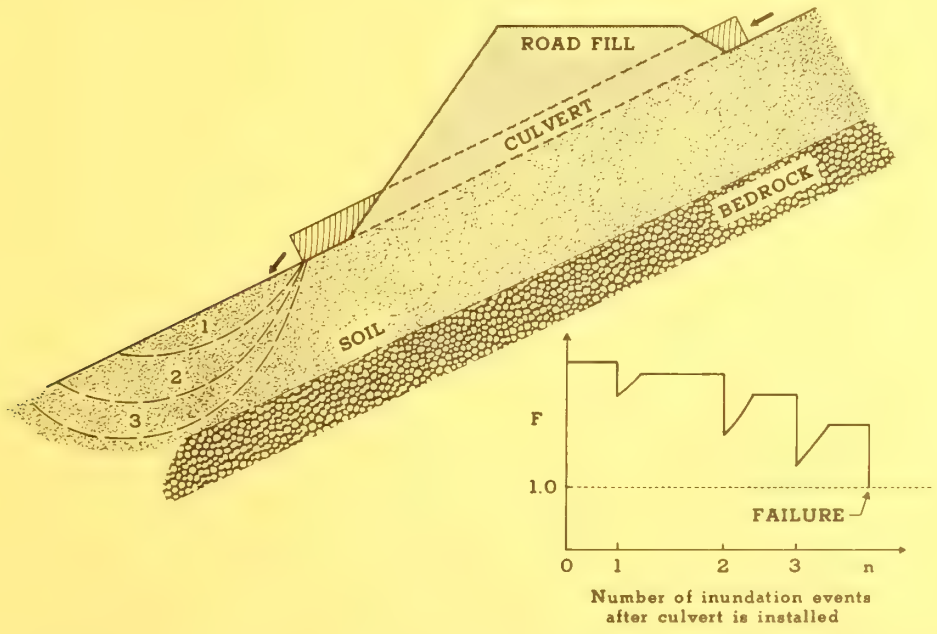

Figure 1--*Potential progressive weakening of a soil mass after inundation of soil by culvert outflow.*

SUMMARY

Soil aggregation and mode of wetting during shear tests of two apparently cohesionless soils caused angles of internal friction of saturated soil to be 9.5°-11° smaller than angles of internal friction of dry soil. Amount of water-stable aggregates was 23 to 35 percent less after saturation of soil samples by immersion than after saturation of samples under tension. Because mode of wetting of some apparently cohesionless soils may affect their strength parameters, the field conditions of wetting soils must be considered when strength test procedures are planned.

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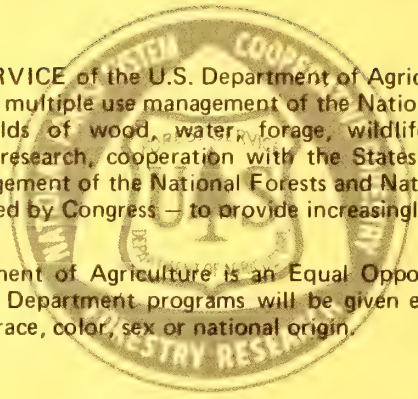

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

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FISHING AND OTHER RECREATION BEHAVIOR AT HIGH-MOUNTAIN LAKES IN WASHINGTON STATE

by

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ABSTRACT

Results of a 2-year participant observation study of recreational activities at seven high-mountain lakes in unroaded areas of Washington State are reported. The data indicate that access-related factors such as distance--elevation to gain--and the presence and type of trail seemed to account for the amount and kind of use occurring at the lakes.

Anglers fished an average of less than 2 hours per day, and 40 percent caught no fish. A variety of reasons were given for visiting the lakes--fishing was only one; and 80 percent of the fishermen cited some other primary motive for visiting the lakes studied. More than half the anglers gave reasons other than catching fish or providing food as their main reason for fishing.

These data suggest (1) the need for sociological as well as biological data as the basis for high lake management, (2) limitations on the potential of managing visitation at such lakes by manipulating the fishery, (3) the importance of lake shore, campsites, and trails as the focal point of use, and (4) the need for management to preserve fishing as an important part of the high-lake recreation experience for many visitors.

KEYWORDS: Recreation, recreationists, fishing, management (forest), land management, Washington.

*At the time of this study, the authors were Recreation Research Project Leader (now Congressional Fellow, USDA Forest Service, Division of Legislative Affairs) and Research Social Scientist (now Recreation Research Project Leader), USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Seattle; and Cooperative Recreation Research Assistant, University of Washington, College of Forest Resources, Seattle.

INTRODUCTION

The rapid increase of recreation use (and its associated impacts) at high-mountain lakes in unroaded areas is of growing concern to resource managers. In the Pacific Northwest, for example, records show visits to classified Wilderness increased over 70 percent between 1966 and 1973.[1/] The growing use of roadless areas often has been accompanied by increasing demands for their designation as wilderness or some other permanent, roadless state where people can pursue a variety of recreational activities such as hiking, fishing, and hunting.

High-lake fisheries are thought to play an important role in backcountry and wilderness because most recreation takes place around lakes and streams. Users show strong preference for lakes over streams (Brown and Schomaker 1974).

Concern about increasing high-lake use led to our involvement in an interdisciplinary case study of seven high-mountain lakes in the Alpine Lakes region of Washington State's Snoqualmie and Wenatchee National Forests. Great controversy then surrounded the future status of this area, a large part of which has since been designated as Wilderness (Alpine Lakes Management Act of 1976, PL 94-357). The area is blessed with hundreds of high lakes which attract growing numbers of recreationists. At many lakes, physical site impacts from recreation use had become a concern, and managers proposed manipulating the fishery to modify visitation (fig. 1). Managers and a prominent citizens group, the Alpine Lakes Preservation Society (ALPS), called for research to determine the role of fishing in recreation use of the area's high lakes so that effective management could be planned.

PREVIOUS RESEARCH ON FISHING

There have been relatively few studies focused on the human behavior aspects of fishing, particularly in roadless (backcountry or wilderness) environments. A recent unpublished bibliography lists just over 100 studies of sport anglers.[2/] Some of these studies have looked at who fishes and why--but most of the literature and research on sport fishing has focused on quantity and quality of the catch as a criterion of a successful trip, and recreational fishery management (Webb 1968; Taft 1947; Bryan 1976, 1977). The dominant perspective emphasizes fishing success--while ignoring other satisfactions and pleasures related to fishing.

[1/] USDA Forest Service, Region 6, Wilderness Use Statistics. Portland, Oregon.

[2/] "Studies of sport anglers: an annotated bibliography," by Thomas E. Dailey. Unpublished data available from Recreation Research Unit 4507 University Way, Seattle, Washington 98101.

Figure 1.--High lake fisheries are thought to play an important role in backcountry areas. Physical impacts from recreation use is of concern to resource managers.

Since the mid-1960's, some managers and several studies have identified broader aspects of the fishing experience which sportsmen deem important. A recent emphasis has been placed on "boat days" (or fishing days) as the product of sport-fishing management (Bryan 1974). And, in spite of the wide diversity of research methods employed in past research and types of fishermen studied, there is surprising consistency in the results so far.

In none of the studies reviewed was catching fish cited as the single most important satisfaction derived from fishing. Escape from everyday tension and pressures, appreciation of natural beauty, companionship, and challenge are frequently mentioned as important components of the fishing experience (Davis 1967; Knopf et al. 1973; Hoagland 1973; Bryan 1974; Bryan 1976; Moeller and Engelken 1972; Bassett et al. 1972; Cooper 1973; Doll and Phillips 1972; Andrews et al. 1972; Spaulding 1970; Hampton and Lackey 1975). It seems apparent that the nature of the fishing experience goes far beyond the actual taking of fish--just as hunting has been found to encompass much more than simply bagging game (Potter et al. 1973; Hendee and Schoenfeld 1973).

The few studies of fishermen in backcountry or wilderness settings indicate similar findings. For example, fishermen in Utah's High Unitas Primitive Area reported fishing as the third most common reason for visiting there (Hoagland 1974), and those studied were similar to other visitors in their concern for the wilderness environment. Lucas (1965) found that a majority of parties fished on visits to the Boundary Waters Canoe Area and that although the findings varied according to type of user (canoeist, day user, auto camper, etc.), a minority of respondents mentioned fishing as their most important activity in the area. Baseline studies of wilderness visitation to several wilderness and backcountry areas indicate that only about half the visitors fish (Hendee et al., in press).

It appears that in all settings studied, fishing is only one of many activities associated with a total outdoor experience in which escape from civilization, enjoyment of the natural environment, and other factors are of major importance. This is summed up by Davis (1967, p. 44) who says of both sport hunting and fishing, "The sport was rarely appealing in only one manner. Although a trip may have been triggered by a single interest, usually a package of changing and interrelated benefits appealed to the participant" (fig. 2).

Despite the fact that studies of fishing consistently identify the interrelationships of fishing motives to a broader outdoor experience, few, if any, have focused directly on how fishing is interwoven and related to other activities. Nor do any past studies directly observe the behavior of fishermen, describing exactly what they do. Most studies of the sociology of fishing have been concerned with reported preferences, attitudes, behavior, and motivations--factors which may have less to do with real behavior than one might think (Wicker 1969, Deutscher 1970, Heberlein 1973, Spaulding 1970).

Figure 2.--Fishing is only one of many activities associated with a total outdoor experience at wilderness and back-country mountain lakes.

STUDY FOCUS

The study reported in this paper is concerned with the sociology of high-lake fishing. A companion study focused on physical-biological aspects.[3/] Information needed for high-lake management requires a marriage of biological and sociological research. Information is needed on what people do at high lakes and the satisfactions they derive from the recreational experiences--including fishing. That social data must then be related to the resources' capacity to produce desirable experiences.

3/ The physical and biological data were collected under the supervision of Dr. Richard Whitney, Leader, Cooperative Research Unit, Bureau of Sport Fisheries and Wildlife, College of Fisheries, University of Washington. The findings of this phase of the high-lake study are reported in Bengston, Clifford (1973), "Some Physical and Biological Features of Eight Highland Lakes in the Wenatchee and Snoqualmie National Forests." Unpublished report on file, College of Fisheries, Univ. of Washington, 84 p.

Our study of recreation behavior at high lakes focused on several research questions:

1. Who visits the lakes?
2. How much do they fish and how much do they catch?
3. What is the role, importance, and meaning of fishing in relation to other high-lake activities?
4. What factors seem to affect the nature and extent of fishing at the lakes?
5. How important are fishing and catching fish in prompting recreational use of the lakes?

METHODOLOGY

The research strategy we employed was participant observation (Gold 1958, Campbell 1970). This approach seemed appropriate because of the open-ended exploratory nature of the questions we were studying and the general lack of information on what behaviors constitute a visit to high-mountain lakes (Clark 1977). Participant observation affords an array of specific approaches for describing behavior and determining its meaning through the researcher's direct interaction with participants.

Data for this study were collected over two summers--1973 and 1974. The basic role assumed during the 1st year of data collection was that of *complete participant* (Campbell 1970). That is, the research staff engaged in activities similar to other visitors to the area. This approach allowed observation of recreation activities without affecting the behavior observed. As a participant, the researcher also gains some feeling for the meaning of the activities observed. That is, the researcher gains insight into the qualitative aspects of the experience which could not be obtained by an outsider who only observes and does not participate in the activity under study.

During the first summer, we maximized opportunities for observing high-lake visitors. We focused primarily on weekends and at those lakes where use was most likely to occur. Ten to 14 days were spent at each lake (a total of 50 days for all lakes) by one or two trained observers. We were not concerned at this time with the representativeness of the lakes, the users, or their behavior. Rather, we sought to discover possible relationships which would require more systematic procedures to verify.

The activities of each lake visitor were recorded, particularly fishing behavior. Detailed notes were made of all anglers' activities, and nonfishing behavior was observed at least every half hour. The location of the behavior relative to campsites and lakeshores and a general description of the type of activity was recorded.

Based on results of the first summer's work, procedures were modified the 2d year to gather more data on fishing activities such as time spent, motives, the respective importance of fishing compared to other behavior, and so forth. We concentrated on one lake

this year although several of the other lakes were occasionally visited to get comparative data. During this second summer, the researcher assumed a role of *participant-as-observer*. This differs from the complete participant role in that the participant-as-observer assumes a formal role as necessary to gather more complete information about feelings, motives, satisfactions, and so forth through unstructured conversational contacts with users.

These two approaches allowed us to gather extensive observational data the first summer on what visitors to high-mountain lakes do, followed by conversational data the second summer about motives for participating in different activities and the meaning of these activities to participants.

LAKES STUDIED

The seven lakes selected for study offer a variety of recreation experiences and are, in many respects, characteristic of the Alpine Lakes Region. Most of them are included in the new Alpine Lakes Wilderness where managers have already pointed to growing problems of visitor impacts. The lakes selected vary in ease of access, reputation for fishing success, location relative to other lakes, and the amount and type of use. Trailheads to all of the lakes were located within 2 or 3 hours driving time from the heavily populated area around Puget Sound in western Washington (fig. 3).

Figure 3.--Trailheads to the lakes were within 2 to 3 hours driving time of the heavily populated Puget Sound area.

Tables 1 and 2 describe the lakes' physical and biological characteristics, as well as access data and the extent of our observations. Four distinct high-lake settings were selected, three of

Table 1--*Physical and biological data on high lakes studied*[1/]

Study setting number	Name of lake	Elevation	Size of lake	Maximum depth	Summer water temperature		Water clarity	Fish age class	Total fish length	When last stocked[2/]	Fish species
					Maximum	Minimum					
		Feet	Acres	Feet	°F.	°F.	Feet	Years	Inches		
1	Lake Stuart	5,064	40	58	63	46	37	1-4	4.4-10.9	1972	Cutthroat
2	Lake Flora	5,680	8	46	62	53	34	2-5	7.6-11.6	1966	Cutthroat
	Lake Brigham	5,840	4	10	59	59	--	3/	3/	1971	3/
	Top Lake	4,600	6	10	65	65	--	3/	3/	1961	3/
3	Pear Lake	4,809	15	83	64	42	40.5	2-4	6.5-11.1	1968	Rainbow
	Peach Lake	4,907	8	73	57	47	46	2-6	7.8-10.7	1972	Cutthroat Rainbow
4	Lake Julius	5,190	12.8	61	59	46	33	1-4	5.2-10.4	1967	Cutthroat
	Lake Eileen	5,508	25	73	56	47	40.5	1-4	4.4-9.8	1971	Cutthroat

1/ Source of this data is in Bengston, 1973 (see footnote 3).

2/ State Game Department records of plants may be incomplete for some lakes.

3/ These shallow lakes contained very few fish but attracted some fishing. Nets left overnight by the University of Washington College of Fisheries data collection team failed to capture any fish, but a very few fish were reported caught by fishermen.

Table 2--*Access-related data and extent of observations at high lakes*

Study setting number	Name of lake	Elevation to gain	Shortest access trail distance	Possible means of access			Type of trail	Days observed		Visitors observed[1/]	
				Foot	Horse	Trailbike		Year 1	Year 2	Year 1	Year 2
		Feet	Miles								
1	Lake Stuart	1,660	5.7	Yes	After Sept. 8	No	Terminal	14	22	222	449
2	Lake Flora	3,480	11.5	Yes	Yes	Part way	Loop	10	--	39	--
	Lake Brigham	3,640	12.0	Yes	Yes	Part way					
	Top Lake	1,050	4.7	Yes	Yes	Part way					
3	Pear Lake	1,339	5.6	Yes	Yes	Part way	Loop	12	--	73	--
	Peach Lake	1,740	6.0	Yes	Part way[2/]	Part way	No trail last 1/2 mi.				
4	Lake Julius	2,230	6.0	Yes	Yes	Yes	Loop	14	7	110	36
	Lake Eileen	2,530	6.5	Yes	Part way[2/]	Part way					
Totals								50	29	444	485

1/ Total visitors observed during both summers are indicated, including those who were not observed during their entire stay.

2/ The first year of the study (1973), trailbike access was possible part way into Top, Pear, Peach, and Eileen Lakes, and all the way to Lake Julius. The trail to Lake Julius was closed to trailbikes in 1974 by the Wenatchee National Forest.

them including two or more lakes. Lake Stuart, the largest lake, was the only one not located relatively close to at least one other lake.

All of the lakes are between 4,600 and 5,800 feet above sea level in the Hudsonian life zone. They ranged from 4 to 40 acres in size. All were clear and cold containing cutthroat or rainbow trout. The capture of fish with a gill net in each lake indicated the fish ranged from 1 to 6 years old and from 111 to 282 millimeters (4.4 to 11.6 inches). Almost all of the fish appeared to be the result of stocking by the Washington State Game Department.

LIMITATIONS OF THE DATA

The extent to which results can be generalized from the study design warrants comment before discussion of results. Certainly, the study design precludes definitive statements about the representativeness of users or their behavior over time or space. The participant observation study design maximizes discovery of relationships and the meaning of an activity to participants through direct interaction of the observer. Such results can be revealing, particularly when they question existing conjecture and folklore about an activity that may be based largely on informal impressions.

The following study results, based on observational and conversational data, reveal the complex relationships between fishing and other behavior at the high lakes studied. We are eager to use the insights gained from this study to help point the way to more definitive study using other research methods, and more knowledgeable management in the future.

RESULTS AND DISCUSSION

Profile of Users

Through observations and conversations with visitors to the lakes, we collected descriptive information about their individual and group characteristics and their previous backcountry and fishing experiences. The data for the first summer are summarized here in the text.

Observations of all users during the first summer (N = 444) revealed the following:

1. Three-fourths of the visitors we saw were male.

2. Half appeared to be adults between 20 and 40 years old. Another third were young people, 12-19 years old.

3. Most people came with others. Most of the groups were small, family or friendship groups. About one-third were groups of male peers, one-fourth were families, and one-fourth were mixed couples. Only about 10 percent of the

parties were single persons or organization groups. Nearly 40 percent of the individuals observed during the summer belong to 11 organized groups that visited the lakes during observation periods.

Conversation contacts with roughly half of the people observed indicated that:[4/]

1. Eighty percent were from urban rather than rural areas.

2. Most were from the more urbanized western Washington (70 percent), about one-fifth from eastern Washington, and only 8 percent were from outside the State.

3. Most of the visitors we contacted had previous backcountry experience, and only about one-fourth had less than 2 years experience. About 40 percent of the visitors had been to the same lake before. Another fourth had been to the general area in the past. (Anglers appeared to have more backcountry experience than nonanglers.)

4. Nearly half the visitors had not fished in the backcountry before, and only about one-fourth had more than 5 years of experience as backcountry fishermen.

This profile of users has important research and management implications. The most striking fact is that most backcountry users visit the lakes in groups. The importance of the group as a reference point will be discussed later in greater detail.

Extent of Activity

FACTORS AFFECTING USE

Several factors seem to be related to the nature and extent of use. Our data and observations suggest the following relationships.

Ease of access, reflected by the distance and elevation to be conquered, seemed directly related to the amount of use.[5/] Lake Stuart and Lake Julius, the easiest to reach (including necessary travel on backcountry roads), attracted the heaviest use--both overnight and day use.

[4/] Conversational contacts were made primarily with those people we observed fishing. About 20 percent of these contacts were with nonfishermen.

[5/] An unpublished study suggests that important correlates of use include whether or not sites are established at lakes, elevation at which sites are located, and trailhead accessibility. Stuart, Thomas W. 1973. Explanatory Models of Wilderness Use: Glacier National Park, 1973. Unpublished manuscript, 11 p., mimeo. Available from School of Forestry and Conservation, Univ. of California, Berkeley.

Lakes that did not have formal trails for access (Peach Lake and Lake Brigham) received much less use despite the fact that they were less than a mile from other lakes on the trail.

Whether or not the lake was on a terminal or loop trail also affected use. Loop trails were associated with stopovers by users on longer trips and some use by persons traveling from a base camp located at other locations. Destination trails were sometimes associated with concentrations of users less able to move on to other lakes to avoid crowding.

Horse use seemed to account for some visitation that might not otherwise have occurred at more distant lakes, particularly Lake Flora and Lake Brigham.

From our observations, it seems apparent that these access factors--distance, elevation to gain, trail or no trail, loop or terminal--are major items for land managers to consider for understanding and influencing patterns of use at high-lake settings (fig. 4).

Figure 4.--Access factors such as distance from trailhead, elevation to gain, and type of trail influence use patterns at high mountain lakes.

Fishing Activity

Fishing often is assumed to be the major activity and primary motive for visiting high mountain lakes. Perhaps this was so before the popularity of backcountry and wilderness recreation increased during the past decade, and perhaps some remote lakes still are visited primarily by fishermen. But, at the seven lakes we studied (table 3), less than half the recreationists we observed (41.6 percent) fished during their stay. And nearly half of the parties we observed (42 percent) contained no fishermen. As previously mentioned, baseline studies of wilderness use reveal similar findings in that about 50 percent of the visitors report that they fished during backcountry trips (Hendee et al., in press).

Table 3--*Proportion of camping parties and individuals observed fishing during their high-lake stay*

Visitors	Camping parties	Individuals[1/]
Total number observed	88	376
Percent observed fishing	58	42

[1/] Only visitors observed during their entire stay were included in this table.

We also recorded the amount of time which anglers spent fishing (table 4). On the average, more than half of the fishermen observed (60 percent) fished 1½ hours a day or less during their stay. The mean time spent fishing per day for all fishermen was 1.8 hours--about half the average fishing day of 3 to 4 hours reported after a comprehensive study of fishing by the Outdoor Recreation Resources Review Commission in 1962 (U.S. Bureau of Sport Fisheries and Wildlife 1962).

Table 4--*Number of fishermen among high-lake users, by average time spent fishing*

Users	Average number of hours fished per day while at site									
	Less than 0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	More than 4.0	Total[1/]
Fishermen	38	32	21	16	15	13	3	4	11	153
Percent	25	21	14	10	10	8	2	3	7	100

[1/] Only visitors observed during their entire stay were included in this table.

The relatively low level of fishing activity challenges the stereotyped image of high-lake fishing trips. One wonders what success these fishermen were having, and how success related to the level of fishing activity.

FISHING SUCCESS

Tables 5 and 6 indicate that people obviously did not stop fishing because they were catching legal limits. In fact, about 40 percent of them caught nothing. Only about 12 percent averaged 4 or more fish per day during their stay, compared to the daily legal catch limit of 12 fish.

Table 5--*Fishing success per day by individual high-lake visitors observed fishing*[1/]

Fishermen	Average number of fish caught per day							
	0	0+ to 1.0	1.0+ to 2.0	2.0+ to 3.0	3.0+ to 4.0	4.0+ to 5.0	5.0+	Total[1/]
Percent	37	29	12	6	7	4	5	100
Number	57	44	19	9	11	6	8	153

[1/] Only visitors observed during their entire stay were included in this table.

Table 6--*Fishing success per day by parties containing at least one fisherman*

Parties with at least one fisherman	Average number of fish caught per day by parties							
	0	0+ to 1.0	1.0+ to 2.0	2.0+ to 3.0	3.0+ to 4.0	4.0+ to 5.0	5.0+	Total[1/]
Percent	31	12	12	4	10	6	25	100
Number	16	6	6	2	5	3	13	51

[1/] Only visitors observed during their entire stay were included in this table.

Success rates were not much better when calculated on a group basis. Over 30 percent of the parties caught no fish and only 25 percent of the parties averaged over five fish a day.

This raises questions about whether the fishermen were catching all they wanted or needed. How important was catching fish to their angling experience? What role did fishing play in their overall high-lake recreation? These questions are addressed later in this paper after some other observations that help explain the appeal of fishing are described.

RELATED SOCIAL BEHAVIOR

The low level of fishing activity and the relatively few fish caught stimulated our curiosity about the relationship of fishing to the overall high-lake recreation experience. To explore this issue, we related fishing to the social nature of the activity. We recorded where people fished in relation to other individuals from their own and other parties and how much the fishermen conversed with companions and others while fishing. This was thought to be potentially important because studies indicate that wilderness and backcountry recreation are characterized by intense socializing within the party and an aversion to contact with persons from other parties (Hendee et al. 1968; Stankey 1973). The same has been found true for hunting (Potter et al. 1973).

DISTANCE FROM OTHER PEOPLE--TERRITORIALITY

The social nature of fishing was characterized by the spatial relationships fishermen established between themselves and members of their own and other parties (table 7). The apparent affinity for companions and aversion to strangers was evident. Eighty percent of the fishermen carried on most of their activity within about 20 feet of a companion, but 75 percent remained 100 feet or more from persons in other parties. Territorial norms appeared to be operating, but the territory seemed to belong to the group and was quite freely shared by members of the same party.

Table 7--*Distance maintained from companions and members of other parties*

Fishermen	Distance from other people while fishing[1/]			
	Near	Medium	Far	Total
	- - - - Number fishermen observed - - - -			
Distance from own party				
Percent	82	16	3	100
Number	120	23	4	147
Distance from other parties				
Percent	4	21	75	100
Number	6	33	115	154

[1/] Distance fished from others was roughly categorized as follows: Near--within 20 feet of others; medium--within 20-100 feet of others; far--more than 100 feet from others.

Most of those we observed seemed to respect the fishing territory established by another group's prior use. For example, on numerous occasions, two groups were observed fishing several hundred yards apart--one at a more favored fishing spot. Several minutes after the first group left the favored spot, the second group would move there. We observed, however, that the first group had evidently established its right to the spot by prior use, and would often return to the spot even though the second group was there.

The greater the density of people at the lake, the more likely were fishermen to infringe on another group's fishing territory. Under crowded conditions, anglers would move to an area already occupied rather than forego fishing or wait to try at a different time. Below some as-yet-undetermined threshold of crowding, the lake apparently was perceived as a place where at least the illusion of isolation and noninvolvement with strangers could be maintained. Above that threshold, the norm did not appear to operate.

At most of the lakes the campsites' territories did not include the lake shore. This made the shoreline a public place where territory was established by a fishermen's presence, or, occasionally, by his prior use. Camps located next to the lake, however, appeared to establish a more inviolate territory. Regardless of the density of users at a lake, most fishermen confined their activity to the public places along the shoreline or adjacent to their own camp. They seldom fished from shore areas which were a part of another group's camp territory.

CONVERSATION WHILE FISHING

Table 8 indicates the amount of conversation we observed between fishermen and their companions and with strangers from other parties. These data clearly indicate the importance of

Table 8--*Amount of conversation while fishing between fishermen and their companions and members of other parties*

Fishermen	Amount of conversation while fishing[1/]			
	Much	Some	None	Total
	- - - Number fishermen observed - - -			
Talking with own party members				
Percent	32	58	10	100
Number	35	63	11	109
Talking with other party members				
Percent	0	9	91	100
Number	0	13	138	151

[1/] Amount of conversation was categorized as: Much--steady conversation; some--occasional conversation; none--no conversation.

social contact with companions and aversion to contact with other parties. All but 10 percent of the fishermen engaged in at least some conversation with companions while they were fishing, but more than 90 percent did *not* converse with anyone from another party while they fished.

The content of fishermen's conversations seemed to vary according to whether they were talking with companions or with people from other groups. Most conversation among companions revolved around fishing either as a cooperative or as a competitive activity. Cooperative fishing conversation was most evident in male-female couples. Usually the woman would help the man by holding the fishing pole while he removed a fish, suggesting areas where fish might be, and generally encouraging him. Such cooperation also was often observed in father-son pairs, where the father played an instructive, supportive role.

Both competitive and cooperative conversation was common in male-peer groups where conversations centered on reports of progress in catching fish, good-natured rivalry, and information regarding successful types of bait or lures. Whether cooperative or competitive, fishing frequently appeared to take the form of a game in which the tangible reward or prize was the fish, which served as a symbol that the participant had been successful in applying his skill. Although not everyone was successful, most apparently had fun playing the game while they enjoyed the company of companions.

Even when the opportunity existed, verbal contact between members of different groups occurred less frequently than conversation with fellow group members. Such intergroup contacts characteristically revolved around fishing as a shared experience. For example, remarks between parties were often probing as if to determine the extent to which parties shared motives, interests, or expertise that might serve as the basis for continuing the contact. Such contacts were characteristically of much shorter duration than those between members of the same party.

SUMMARY OF FISHING ACTIVITIES

Our observations of fishing activities are revealing. Less than one-half of the high-lake visitors we observed were fishing during their stay. Those who fished spent only a small portion of their available time at the lake fishing, and they caught few fish. They also spent much of their fishing time interacting with members of their own group. The aversion for social contacts outside their party is demonstrated by the distance maintained between parties and the lack of conversation outside their group.

But, how do anglers spend their nonfishing time? Do they behave differently from the lake visitors who do not fish?

Nonfishing Activity

To put fishing in perspective, we observed the nonfishing behavior of fishermen and other visitors. We noted during daylight hours what people were doing, whether they were away from the lake, at the lake but away from camp, or actually in the camp. These data are presented in table 9.

Table 9--*Time spent during daylight hours at various locations at and away from the lakes*

Location	Number of days at lake							
	Day users		2 days		3+ days		Total	
	Fishermen (N=21)	Non-fishermen (N=68)	Fishermen (N=95)	Non-fishermen (N=110)	Fishermen (N=33)	Non-fishermen (N=26)	Fishermen (N=149)	Non-fishermen (N=204)
	Percent of time							
Observed:								
In camp	0	23	63	69	59	74	58	67
At lake but not fishing	7	44	12	18	8	15	10	19
At lake fishing	68	--	22	--	26	--	25	--
Away from lake	25	33	3	13	7	11	7	14
Total	100	100	100	100	100	100	100	100
Not observed[1/]	12	37	17	20	12	18	15	21

[1/] Most unobserved time was probably spent either in camp or away from the lake since it was easier to observe users who were at the lakeshore.

Both anglers and nonanglers spent part of their waking time away from the lake (fishermen 7 percent, nonfishermen 11 percent). They explored the area, looked at scenery, walked, and talked--usually within a half-mile of the lake and on or near the trails. They were almost always with companions.

With the exception of day users, fishermen and nonfishermen spent a major portion of their waking time in camp. (Fishermen on the average spent 57 percent, nonfishermen 67 percent.) The importance of the campsite as a hub of activities for all overnight visitors was impressive. Much of the activity in or around the camp area was related to the functional aspects of living outdoors--pitching and breaking camp, cooking and cleaning up after meals, building fires, etc. A large portion of camp time, however, was spent in leisure activities--reading a book, playing cards or a more active game, or just sitting around talking with companions.

Finally, both anglers and nonanglers spent part of their available, waking time at the lakeshore, 35 percent and 19 percent respectively. Nonfishermen, for the most part, spent lakeshore time in a small range of passive-appreciate activities, such as relaxing in the sun while talking to a friend or viewing the scenery. Often they conversed with fishing companions. Frequently, nonfishermen would comment about fish jumping or swimming--and a few people were observed feeding fish.

Fishermen spent their time at the shore in much the same manner as nonfishermen except they spent more than two-thirds of it holding a fishing rod. The only difference observed between these two groups was that much of the anglers' time at the lakeshore was spent fishing. In all other aspects, the behavior of fishermen and nonfishermen appeared similar.

There are interesting variations in the patterns of activity which were apparently related to the number of days a party spent at the site. Day hiker anglers commonly spent several hours fishing and did little else while at the lake. Day anglers typically arrived earlier in the day than those planning a longer stay. They found a good spot and fished for several hours then packed up their catch and went home. Success seemed important to these day anglers. The non-fishing day user spent a large part of his time at the lakeshore (44 percent), more than twice as much as did those who stayed overnight.

Most people spent 2 days at the lake, camping overnight. Those who fished during their 2-day stay are not so easily characterized as day hikers. Those who fished typically did so for a total of 2 to 3 hours, but spread over several occasions during the 2-day period. Contrary to the popular stereotype, few of these people fished early in the morning or late in the evening, a finding supported by other research (Graham 1973, Sohn 1968). Most arose around 8:00 or 9:00 a.m. to fix a leisurely breakfast and maintain camp, and spent the early evening sitting around the campfire. Most of their fishing was done in the mid-afternoon of the 1st and mid-morning of the 2d day. And unlike day-hike fishermen who usually packed out their fish, these overnight fishermen ate their catch on the spot--often for dinner the first day and for late breakfast on the second.

Anglers who spent 3 or more days at the lake predictably spent more time fishing--nearly 7 hours on the average--and spread their fishing time over at least three separate occasions during their stay. Like the 2-day visitors, they were generally casual about fishing and ate most of their fish at the lake.

The nonfishermen who stayed for 2 or more days spent about half as much time at the lake as fishermen. More of their time was spent in camp or in exploring away from the lake.

Clearly, the lakeshore presents the opportunity for a variety of activities in addition to fishing--for fishermen as well as for those who do not fish. The activity of fish in the lake can be a source of satisfaction for nonfishermen as well as for anglers; and, we should mention, fishing sometimes conflicts with other lakeshore activity and visa versa. For example, as lakeshore territories were established by either fishermen or nonfishermen, whether for fishing, swimming, rafting, skipping rocks, or just playing along the shore, their presence precluded activities by others (or set the stage for conflict).

For many, fishing seemed an appealing activity facilitating nature appreciation and social contact with companions. But with the exception of the quest for fish, it appears similar to other high-lake behavior--not very different from sitting on a log gazing at the lake or mountains, throwing rocks into the water, photographin the sunset over a lake, strolling along the shore talking with a friend, or the many other things that we observed people doing during their stay at the lakes.

THE IMPORTANCE OF FISHING AS A HIGH-LAKE ATTRACTION

During both summers, participant observers informally talked with lake visitors to find out why they came to the lake and what anglers liked about fishing. Tables 10 and 11 indicate primary reasons for visiting the lake and for fishing.

One generalization consistently emerging from our informal conversational contacts is that people express a variety of reasons for visiting high lakes (table 10). Fishing was only one reason mentioned, and most fishermen (all but 19 percent) even gave higher priority to other motives. Fishing was second to nature and scenery appreciation as the most frequently mentioned, primary reason for the visit, followed closely by companionship. Escaping daily routine, relaxation, exploration, solitude-comtemplation, hiking, and photography also were mentioned as *primary* motives for some visitors.

When we asked anglers why they fished, several motives were also given (table 11). Twenty-five percent said catching fish and another 19 percent said providing food was their main reason for fishing. But, more than half the fishermen gave other primary reasons such as relaxation, to pass the time, companionship, nature appreciation, etc. (fig. 5).

Table 10-- *Primary reasons given for visiting a high lake*

Primary reason	Fishermen				Nonfishermen			
	1973	1974	Total	Percent	1973	1974	Total	Percent
	- - - - Number - - - -				- - - - Number - - - -			
Nature/scenery	12	31	43	29	8	25	33	29
Fishing	13	15	28	19	--	--	--	--
Companionship	5	17	22	15	3	14	17	15
Escape	2	11	13	9	5	17	22	19
Relaxation	3	6	9	6	6	6	12	10
Photography	2	1	3	2	2	1	3	3
Exploration	3	5	8	5	--	2	2	2
Solitude/ contemplation	3	3	6	4	--	4	4	4
Hiking	1	4	5	3	1	5	6	5
Peacefulness	--	5	5	3	--	5	5	4
Exercise	--	4	4	3	--	8	8	7
Mountain climbing	--	3	3	2	--	2	2	2
Total	44	105	149	100	25	89	114	100

Table 11--*Primary reasons given for fishing in 1974*

Primary reason	Individuals reporting	
	Number	Percent
To catch fish	25	25
Relaxation	24	24
To pass time	20	20
Provide food	19	19
Companionship	16	16
Nature/scenery	14	14
Skill/challenge	11	11
Contemplation	1	1
Total	101	100

Figure 5.--Although catching fish is the goal for many fishermen, only 25 percent said catching fish was their main reason for fishing.

We can now provide at least tentative answers to the questions raised earlier: How important is catching fish to the fishing experience? Were fishermen catching all the fish they wanted?

Catching fish seemed to be desirable, but not absolutely necessary to an enjoyable fishing experience. The attitudes of many fishermen appeared sympathetic with the opinion of one angler who said, "I like to catch a few fish, but that's a bonus ... fishing is just a nice way to relax and pass the time up here in the mountains."

For some anglers, catching fish *is* the primary reason for fishing. But this did not seem true for most of the fishermen we observed or talked to. The high-mountain lake experience of these anglers probably would not be complete without fishing, but neither would it be complete without other aspects of the experience.

Fishing and the chance of catching fish may have prompted the trip for some people, but when you remove the fish from consideration, the fishing behavior seemed a path to the same kind of companionship and nature appreciation sought by nonfishermen through other activities at the same high lakes. Similar results have been found in research on hunting (Potter et al. 1973).

IMPLICATIONS FOR HIGH-LAKE MANAGEMENT

The foregoing data describe the behavior and motives of visitors to several high-mountain lakes based on two summers of observation and conversational contacts. This research is exploratory; other, research methods are needed to establish the generality of our findings as applied to other lakes or users. But, the implications for management of such areas are many if, indeed, the relationships we observed hold true. Several of the more important implications are discussed below.

Integrating Biological and Social Perspectives: Perhaps the most striking finding is the complex nature of high-lake use. High lakes are a valuable recreational-esthetic asset attracting fishermen and nonfishermen alike. This study and others indicate fishing is an important part of the backcountry experience for about half of the visitors. But both fishing and nonfishing activities yield many other satisfactions, and the focal point for both kinds of users is the lake. Clearly, effective high-lake management will require integration of both biological and social data to develop management programs which provide quality recreation experiences for all high-lake users.

Managing Use With the Fishery: Due to the rapid increase in use and associated impacts on high lakes, managers are giving serious thought to managing the number, size, and species of fish in an effort to modify recreational use patterns. For example, a resolution by the Intermountain Chapter of the American Fisheries Society promotes stocking of high lakes as a means for distributing and controlling recreation use.6/ Our data give some basis for

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6/ American Fishery Society Newsletter, p. 10, Sept.-Oct., 1973. Also see discussion of this issue in Schoenfeld and Hendee 1977.

assessing the probability of attracting, dispersing, or repelling visitors by manipulating the fishery.

Specifically, nearly half the users we observed are unlikely to be affected by changes in the fishery since almost 60 percent do not fish and 40 percent of the parties contained no fishermen. For the nonfishermen, factors other than the fishery must be considered to affect their use patterns.

But what about the fishermen--will modifying the fishery change their use? Our data suggest that for those ardent fishermen who go to the lakes primarily to fish and fish primarily to catch fish--manipulating the fishery would probably change their behavior. If fishery management increased or decreased available numbers and size of fish (and that fact was advertised), ardent fishermen would likely choose among the alternative locations accordingly. And, it is possible that in some situations diverting a portion of the fishermen from an overused lake may go a long way towards resolving an overuse problem. This alternative management approach should not be discarded.

For those "incidental" fishermen who visit high lakes primarily for reasons other than fishing, even though they fish, *or* who fish primarily for reasons other than to catch fish, a change in the fishery is less likely to have an effect. For these fishermen, fishing and catching fish seems incidental to the overall back-country experience. Our observations and conversations indicate these incidental fishermen are in the majority at the lakes we observed.

Consequently, manipulating the fishery to modify visitation at high lakes is, at best, a partial solution. In addition to the chance of catching fish, our observations also suggest that access factors--distance, elevation to be gained, and kind of trail--are correlated with both fishing pressure and visitation by nonfishermen.

In any case, users must be made aware of the available high-lake opportunities and the effort required to get to them so choices can be based on the type of experience desired. The fishery is only one of the variables users seem likely to consider. Managers should consider factors in addition to the fishery for controlling use when necessary.

Importance of the Lakeshore, Campsites, and Trails: At the lakes we studied, the location of the campsites and trails seemed very important--both from a user and management perspective. Fishermen and others spent most of their waking time in camp, and nearly all of it was spent either in their camps or at the lake-shore (fig. 6). The remaining time--less than 20 percent--was spent on trails near the lake.

Given the prime attraction of the lake, it is only logical most people would want to camp and play near the lakeshore. And if the

Figure 6.--The lakeshore is the primary attraction and location for most activities at high mountain lakes for fishermen and nonfishermen.

camps are not near the shore, most are at least in view of the lake, a preference documented in other studies (Brown and Schomaker 1974).[7/] This situation presents two potential problems. First, campsites near the shore establish around-the-clock territory for few parties, reducing public space for other users. Particularly penalized may be day users who have no chance to claim territory of their own by establishing an overnight camp.

7/ See footnote 4 for Stuart (1974).

Second, given the large amount of time people spend in camp, the physical impacts near the shore may be considerable. Because the campsite is the focal point for so much activity, it may also be the focal point for substantial environmental impacts. Consequently, at heavily used lakes, it may be desirable to locate (or relocate) campsites and trails away from the lakeshore to reduce *both* social and environmental impacts. If camps are established away from the shore, much of the impact is diverted from the prime attraction for both fishermen and others. When contemplating such action managers should, however, keep in mind the importance of the lake to all users' experience and seek alternative sites judiciously--preferably with at least a view of the lake.

Preserving the Importance of High-Lake Fishing: This study indicates that fishing and catching fish are only a part of the overall backcountry experience for most visitors to the high lakes we observed. But that is not to say that fishing is unimportant in these areas. Fishing at high lakes provides a unique experience derived from the natural setting and the related wilderness activities. The backcountry or wilderness is a place where people can indulge in the notion that one can live off the land. Catching a few fish and eating them in camp with family or friends contributes to the quality of many visitors' experience--and is a goal of many others.

The challenge to resource managers is to recognize the importance and meaning of fishing and catching the fish in relation to the total high-lake recreation experience--to balance the demands for maximum fish production against the esthetic aspects of backcountry and wilderness experiences (Hendee and Schoenfeld 1977). Comprehensive management of the fishing and related high-lake resources is called for and will require close cooperation between fishery and other land use managers and planners (fig. 7).

Figure 7.--Fishing at high lakes provides a unique experience when people may indulge the notion that one can live off the land.

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METRIC CONVERSIONS

1 inch = 2.54 centimeters
1 mile = 1.609 kilometers
1 acre = 0.405 hectare
32°F = 0°C

GPO 985-640

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

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AIR TEMPERATURE AND WIND PROFILES IN AN ALASKAN LOWLAND BLACK SPRUCE STAND

GOVT. DOCUMENTS DEPOSITORY ITEM
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by

Erwin R. Berglund and Richard J. Barney[1/]

ABSTRACT

Temperature and wind profiles were investigated in an Alaskan lowland black spruce stand. Results indicate windspeeds measured 14.8 feet (4.5 meters) above the canopy are over four times faster than those measured at 1.6 feet (0.5 m) above the ground vegetation. Temperature measurements indicated a persistent positive lapse rate between 11.5 and 14.8 feet (3.5-4.5 m). Inversions were apparently more persistent at 0 to 4.9 feet (0-1.5 m) above the ground, regardless of solar energy input.

KEYWORDS: Temperature, windflow, black spruce, *Picea mariana*, Alaska, vegetation, fire behavior (forest), fire control.

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FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

INTRODUCTION

Interior Alaska has vast areas of lowland black spruce (*Picea mariana* (Mill.) B.S.P.). The trees and associated vegetation are distributed in unique mosaic patterns. These patterns reflect the wildfire activity common to this portion of the State. Numerous cities, towns, and villages exist in the interior. Increasing populations find developments in the wild lands adjacent to these communities desirable. A fire management program is necessary to assist land managers and to develop and protect natural resources, human life, and property.

Black spruce sites usually appear to have sparse vegetation with spindly trees. Closer examination reveals substantial fine fuel accumulations, sometimes in excess of 50 tons per acre (112.09 metric tons per hectare). During warm, dry summers these fine fuels can become extremely hazardous. Forest fire management efforts depend not only on knowledge of the fuel's physical characteristics and the diurnal fluctuations in fuel moisture, but also on the wind profiles within the forest stands.

Fuel moisture fluctuations are a function of numerous interrelated factors. Two principal factors are energy and vapor exchanges. Energy is required for the evaporation of water. The water vapor transport phenomenon occurs along partial pressure gradients of water vapor. Field studies often attempt to characterize the energy exchange from measurements of air temperature gradients. Vapor pressure gradients are difficult to measure, and wind profiles are often used to help describe the transport characteristics of vapor and energy.

With knowledge of the influence of vegetative cover on air temperature and wind profiles, forest fire managers can more accurately predict potential fire behavior and rate of fire spread.

The objective of this study was to investigate air temperature and wind profiles in a stand of lowland black spruce.

STUDY AREA

The Bonanza Creek Experimental Forest is 14 air miles (22.5 kilometers) west-southwest of Fairbanks, Alaska. It is at 148°15' W. longitude and 65°45' N. latitude. Elevations range from 550 to 1,650 feet (168-503 m). This typical lowland black spruce stand is on the Tanana River flood plain at a 550-foot (168-m) elevation. The 51-year-old trees average 9.4 feet (2.9 m) in height and 1.05 inches (2.7 centimeters) in diameter at breast height. Stand basal area is 82 square feet per acre (18.8 m^2/ha) with 11,067 stems per acre (27,374 stems/ha). Stand biomass is estimated to be 64.65 tons per acre (144.93 metric tons/ha) (Barney and Van Cleve 1973). This biomass is distributed as follows: moss, 84.5 percent; black spruce trees, 11.1 percent; dead and down material, 1.8 percent; standing dead material, 1.6 percent; and herbaceous vegetation, 1.0 percent.

METHODS

Data were collected at one sampling location in the black spruce stand during the summer of 1972. Instruments were supported on a tower with

horizontal members at these levels (fig. 1A):

Level	Height	
	Feet	Meters
1	1.6	0.5
2	4.9	1.5
3	11.5	3.5
4	14.8	4.5

The 11.5-foot (3.5-m) level approximated the maximum crown height.

Air temperature sensors consisted of Yellow-Springs[2/] thermistors mounted in aluminum radiation shields (Barney 1972). Wind measurements were obtained from modified Freize Airways anemometers that provided a contact closure for each one-twelfth mile of wind passage. These anemometers have a starting threshold windspeed of approximately 2 miles per hour (3.22 km/h). One thermistor and one anemometer were located at each level. Two battery operated Rustrak recorders with dual charts were used. Wind and temperature data from each level were recorded continuously on half the dual chart (fig. 1B).

Data were transcribed at 15-minute intervals. Wind run[3/] measurements were summed over the 15-minute period before each recording of temperatures at the sampling location.

Figure 1.--A, view of tower and instruments; B, recording instruments adjacent to tower.

[2/] The use of trade, firm, or corporation names is for the information and convenience of the reader. Such use does not constitute official endorsement or approval by the U.S. Department of Agriculture.

[3/] Wind run is the total accumulation of miles of wind over time.

The data from 1 overcast day (September 3, 1972) and from 2 clear days (August 30 and September 5, 1972) were analyzed. Data were complete at all levels for these days, and sky conditions were either uniformly overcast or clear.

RESULTS AND DISCUSSION

Air Temperature

Diurnal air temperature variability was less during overcast conditions (fig. 2) than during clear sky conditions (figs. 3 and 4) because of less intense solar radiation and minimized sensible heat generation on the overcast day. Furthermore, cloud cover diffused radiation and distributed the energy more uniformly within the open black spruce stand. Variability was lowest at the 14.8-foot (4.5-m) level. Air circulation at this level was less restricted because it was about 3 feet (1.0 m) above the general canopy level.

Temperature inversions persisted during the overcast day and one clear day (fig. 2 and fig. 4) between the 1.6- and 4.9-foot (0.5- and 1.5-m) levels. A dominant influence may be the substantial moist moss biomass. Approximately 0.38 inch (0.97 cm) of rain September 1 and a possible trace on September 4 may have substantially increased the heat sink potential of the moss. The cool, moist surface would favor shallow inversion development. On August 30 (fig. 3) the inversion was dissipated before 1200 hours, was reestablished between 1300 and 1500 hours, and was dissipated again from 1800 to 2200 hours. Two clear days preceded the clear day, August 30. Sufficient moisture deficit in the moss surface could result in ample sensible heat generation and destroy inversions on August 30.

Lapse rates at 4.9 to 11.5 feet (1.5-3.5 m) in the black spruce reflected active energy exchanges during all days. Both the overcast day (September 3) and one clear day (September 5) exhibited isothermal or positive lapse rates starting about 0900

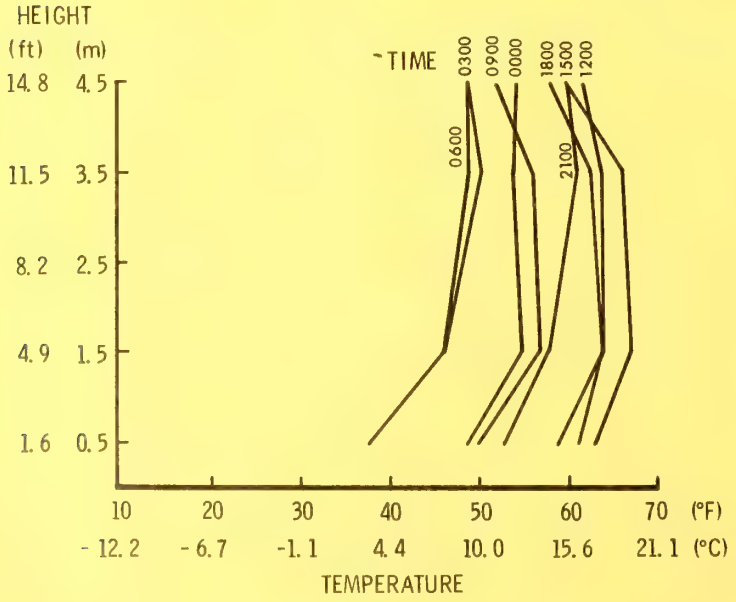

Figure 2.--Temperature profiles during an overcast day, September 3, 1972.

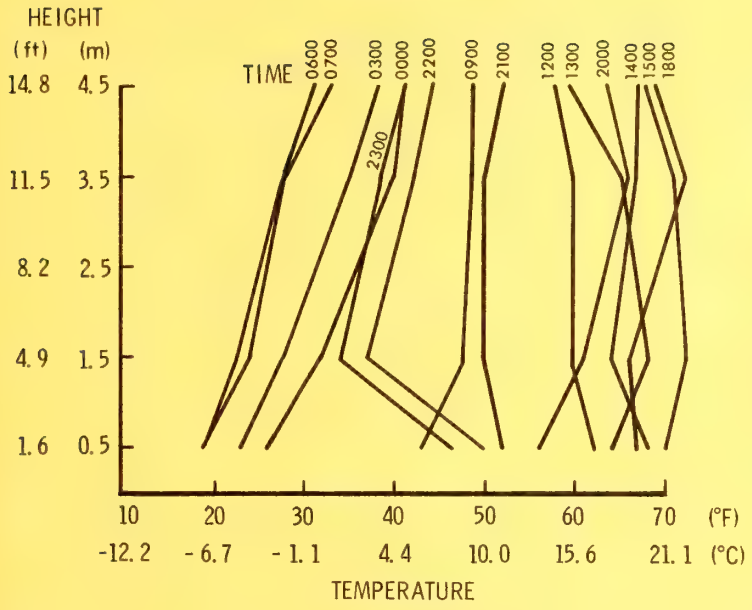

Figure 3.--Temperature profiles during a clear day, August 30, 1972.

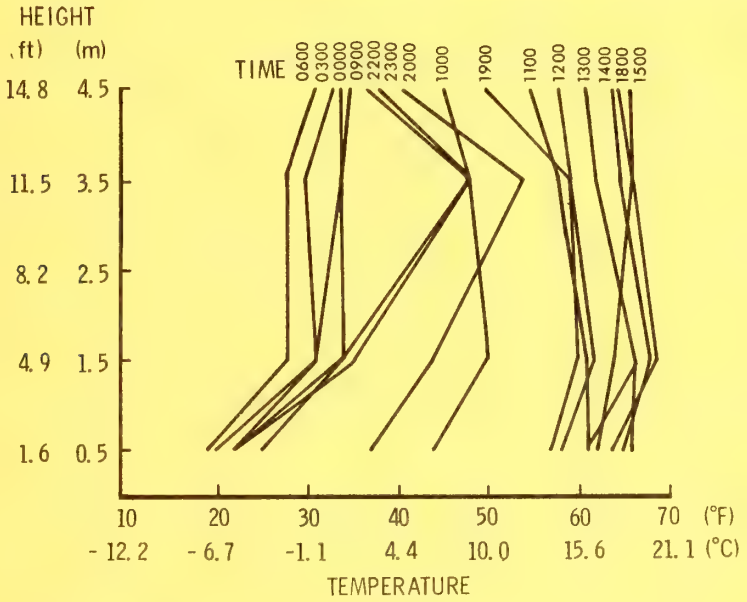

Figure 4.--Temperature profiles during a clear day, September 5, 1972.

hours. These conditions weakly persisted until 1800 to 2000 hours. On September 5 a strong 11°F (6.1°C) inversion developed at 2200 hours. A more complex situation of inversions, isothermals, and positive lapse rates occurred on August 30 throughout the afternoon.

Distinct temperature responses occurred above the black spruce canopy, 11.5 to 14.8 feet (3.5-4.5 m). Progressive warming

during the day indicated positive response by the vegetation to solar radiation. The nocturnal inversion was dissipated on or before 0900 hours. Positive lapse rates persisted after 1800 hours; and on September 5, a strong lapse rate developed from 1900 hours to the end of the day. The persistent positive lapse rates between 11.5 and 14.8 feet (3.5 and 4.5 m) may indicate the thermal storage of the black spruce stand.

Wind

Interior Alaska generally experiences, on the average, minimal wind activity. The massive Alaska Range to the south and southwest of Fairbanks and the Brooks Range across the northern portion of the State shield the interior from much storm activity. Greatest average windspeeds occur from April through October with August and September having average speeds of 5.7 and 5.8 miles per hour (9.2 and 9.3 km/h), respectively, at instrument shelter heights (Searby 1968).

Capabilities for predicting forest fires for suppression efforts can be improved if relationships between free airflow above and beneath a canopy are developed. Windspeeds above a forest canopy may have a logarithmic profile (Munn 1966). Canopy structure dominates air movement within a stand. Tree height, crown geometry, tree spacing, and understory structure all influence air movement. These data indicate a general relationship between above and below canopy wind velocities for this study site. The fire spread prediction model (Rothermel 1972) considers the windspeed at midflame height one of the most essential input variables. Historically, weather for fire danger rating purposes is measured in a clearing and wind is measured at a 20-foot (6.1-m) standard or equivalent (Fischer and Hardy 1972). It is important, therefore, to know which conversion factor is appropriate for various cover types. The 20-foot (6.1-m) standard measurement must be extrapolated to an effective windspeed within the canopy. Because wind is an important variable in the prediction model, a more specific scaling for local canopies is desirable.

Differences in nocturnal and diurnal wind velocity are apparent from analysis of accumulated wind run over time (figs. 5, 6, and 7). Accumulated wind run was proportional to height above the ground surface. The overcast day (fig. 5) exhibited minimal and somewhat erratic wind activity. Wind run was slight from 0000 to 2100 hours and then increased. This increase may have been due to the passage of a large scale weather system.

In contrast, accumulated wind run data under clear sky conditions (figs. 6 and 7) exhibited a different distribution. Nocturnal, downslope winds and diurnal, thermal wind activity may have caused the slope changes in the graphs. If so, nocturnal, downslope winds of low speed were detected only at level 4--the roughness of the black spruce canopy would negate any influence within the stand. The elevation difference between the study site and an adjacent hilltop was 1,100 feet (335 m). These slight, erratic winds were evident from 0000 to 0900 hours on August 30 and from 0000 to 1000 hours on September 5. The approximated windspeeds would be

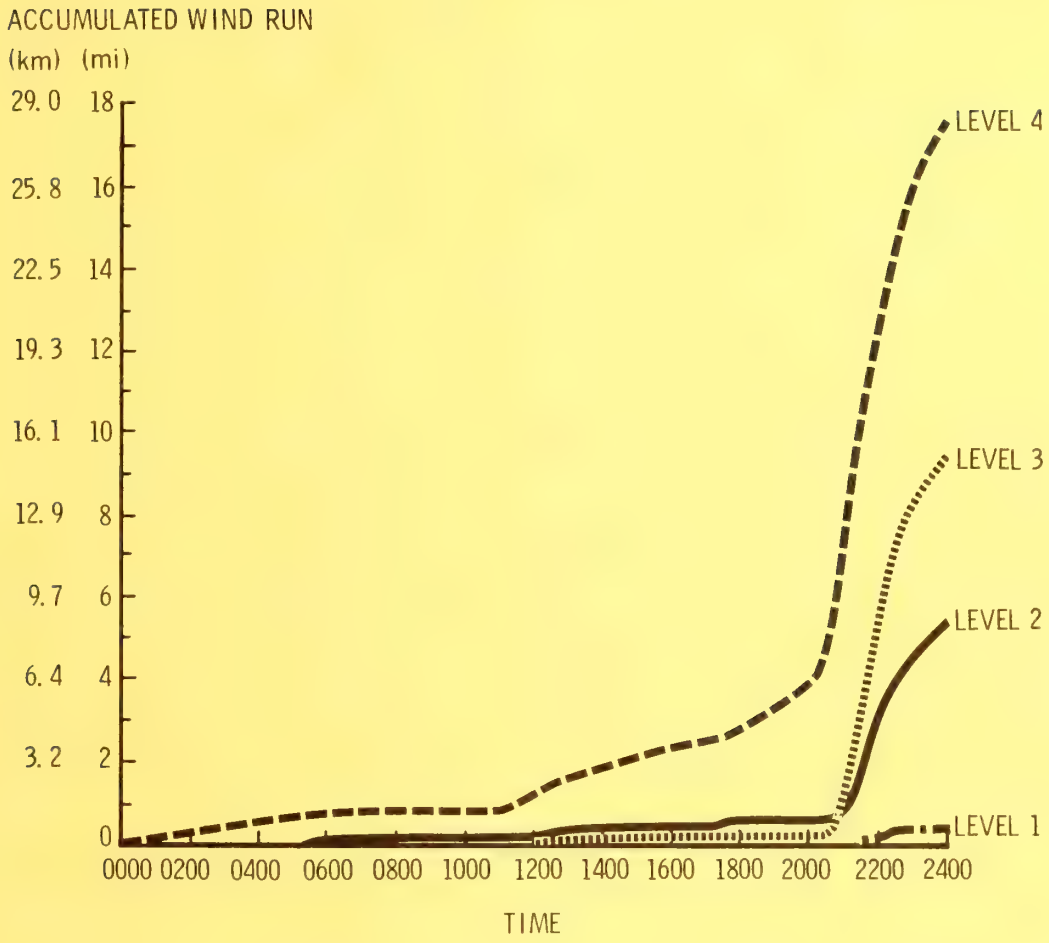

Figure 5.--Accumulated wind run at four levels on an overcast day (September 3, 1972) in a lowland black spruce stand.

0.17 and 0.08 mile per hour (0.27 and 0.13 km/h), respectively, averaged over the 9- and 10-hour periods. Sunrise occurred just before 0800 hours, after which time thermal responses were noted (figs. 3 and 4). The nocturnal winds continued for approximately 1 hour until diurnal, thermally activated winds dominated. Nocturnal, downslope winds began again at 2100 hours on August 30 and 1900 hours on September 5. The winds averaged 0.19 and 0.37 mile per hour (0.31 and 0.60 km/h), respectively (table 1).

Daytime windspeeds were substantially greater than the nocturnal winds as indicated by the steeper slopes of the accumulated wind run figures. Average diurnal and nocturnal

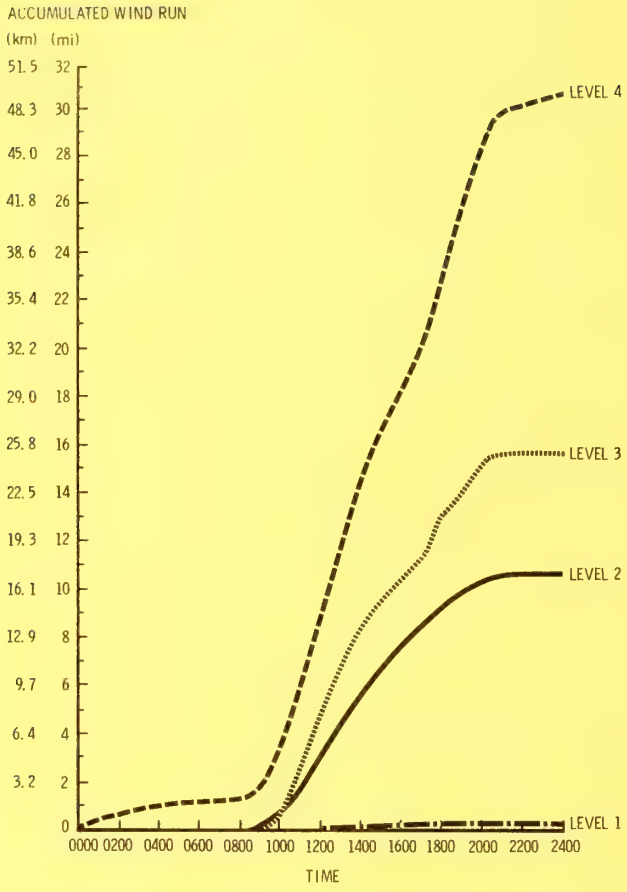

Figure 6.--Accumulated wind run at four levels on a clear day (August 30, 1972) in a lowland black spruce stand.

Figure 7.--Accumulated wind run at four levels on a clear day (September 5, 1972) in a lowland black spruce stand.

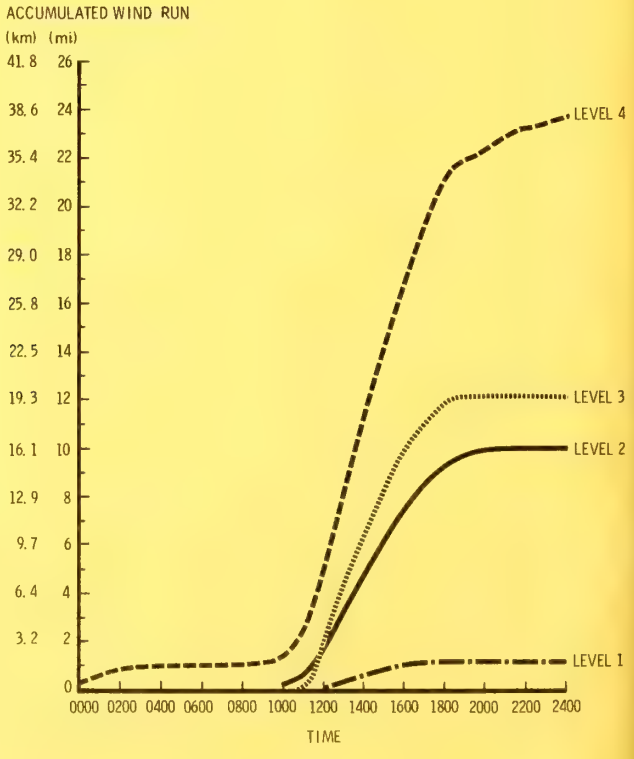

Table 1--*Average windspeeds for diurnal and nocturnal conditions at four levels on clear days, August 30 and September 5, 1972*

Level number and height of wind			August 30						September 5					
			Diurnal		Nocturnal				Diurnal		Nocturnal			
					a.m.		p.m.				a.m.		p.m.	
	ft	m	mi/h	km/h	mi/h	km/h	mi/h	km/h	mi/h	km/h	mi/h	km/h	mi/h	km/h
4	14.8	4.5	2.48	3.99	0.17	0.27	0.19	0.31	2.75	4.43	0.08	0.13	0.37	0.60
3	11.5	3.5	1.39	2.24	0	0	0	0	1.69	2.72	0	0	0	0
2	4.9	1.5	.95	1.53	0	0	0	0	1.26	2.03	0	0	0	0
1	1.6	.5	.03	.05	0	0	0	0	.19	.31	0	0	0	0

windspeeds per level are presented in table 1. Typically, speeds increase with height and are greatest above the canopy level.

The diurnal windspeeds relative to the level 4 data are illustrated in figure 8. Relative speeds increased markedly from 1.6 to 4.9 feet

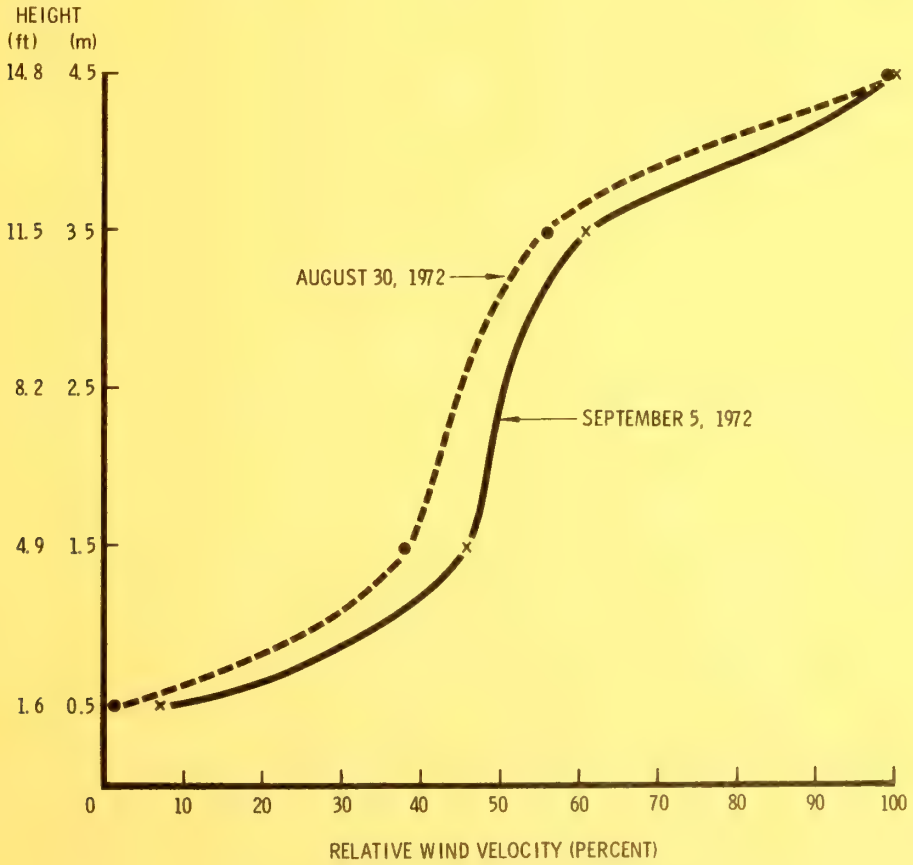

Figure 8.--Approximated relative windspeed on 2 clear days as a percent of windspeed at 14.8-foot (4.5-m) height.

(0.5-1.5 m). Between 4.9 and 11.5 feet (1.5 and 3.5 m), the black spruce crown zone, the relative speeds exhibited much less change. Above 11.5 feet (3.5 m), the top of the crown level, speeds increased rapidly in the free airspace.

Diurnal wind run at levels 1, 2, and 3 for the 2 clear days combined show linear relationships with that of level 4 (table 2). The slopes of the relationships decrease with height. Correlations such as these should enhance potential for predicting wind measurements for fire management purposes. These relationships were developed by eliminating observations when zero wind was observed at level 4.

CONCLUSIONS

Effective forest fire control programs are in need of research to assist in predicting rate of fire spread and fuel moisture relationships. Air temperature and wind variables are important indicators of the energy and water vapor transport phenomena interacting with the physical fuel system; they are also important in predicting spread and behavior of burning fires.

In the lowland black spruce study site, temperature inversions may persist for 1 or more days in the 0- to 4.9-foot (0- to 1.5-m) height surface layer irrespective of inputs of solar energy. This condition may be due to partial shading from the black spruce and the potential heat sink provided by the sizable moss-herbaceous ground cover. This ground cover comprises 84 percent of the stand's total biomass.

Temperatures in the black spruce crown zone, 4.9 to 11.5 feet (1.5-3.5 m) above the ground, indicated active energy exchange processes. Soon after sunrise, isothermal conditions and lapse rates dominated this zone. In-

Table 2--*Results of linear regression analyses comparing wind run data at levels 1, 2, and 3 (dependent variables) with wind run data at level 4 (independent variable)*

Level	n	r^2	a	b	Mean	SD
4	128	0	0	0	5.086	3.473
3	128	0.837	-0.975	0.703	2.602	2.669
2	128	.797	-.335	.4406	1.906	1.714
1	128	.149	-.0567	.0388	.141	.347

NOTE: Level 1 = 1.6 feet (0.5 m); level 2 = 4.9 feet (1.5 m); level 3 = 11.5 feet (3.5 m); level 4 = 14.8 feet (4.5 m); n = number of observations; r^2 = coefficient of determination; a = intercept; b = slope; SD = standard deviation; regression form is Y = a + bx.

versions recurred throughout the clear day of August 30 which indicated complexities unresolved by this study.

Above the black spruce canopy the inversions were dissipated soon after sunrise and lapse rates persisted several hours after sunset. This may indicate substantial thermal storage capacity in the small, dense crowns. Temperatures above the canopy were less erratic than at lower levels and increased with time during the day.

Wind relationships on overcast days may be dominated by large scale weather systems instead of stand conditions. The wind was light and erratic throughout the overcast day (September 3), but windspeed increased markedly after 2100 hours.

Distinct nocturnal and diurnal wind distributions are evident. Analyses of accumulated wind run over time on 2 clear days clearly distinguished between downslope, nocturnal winds and diurnal winds. Nocturnal winds averaged 0.08 to 0.37 mile per hour (0.13-0.60 km/h). They were only detected above the black spruce canopy. The winds ceased about 0900 hours and began about sunset (1900-2100 h).

Average diurnal windspeeds were greatest at the 14.8-foot (4.5-m) level. A substantial reduction occurred at the 11.5-foot (3.5-m)(top of the crown) to the 4.9-foot (1.5-m) level. Below the crown zone at 1.6 feet (0.5 m), winds averaged less than 0.5 mile per hour (0.8 km/h). Linear correlations relate windspeeds within the black spruce canopy.

The preceding information has provided some initial insights into temperature and wind profile relationships within a black spruce stand. The potential exists for developing fire effects models and precise predictions of fire behavior in the flammable lowland black spruce stands of interior Alaska. As fire management activities and decisions become more sophisiticated, the need for improved predictions will increase. The information from this study, however, will provide a first look and, we hope, will be one step toward gaining more sophisticated information in the future.

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GPO 999-825

USDA FOREST SERVICE RESEARCH NOTE

PNW-306 December 1977

ROOT STRENGTH CHANGES AFTER LOGGING IN SOUTHEAST ALASKA

by

R. R. Ziemer and D. N. Swanston[1/]

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ABSTRACT

A crucial factor in the stability of steep forested slopes is the role of plant roots in maintaining the shear strength of soil mantles. Roots add strength to the soil by vertically anchoring through the soil mass into failures in the bedrock and by laterally tying the slope together across zones of weakness or instability. Once the covering vegetation is removed, these roots deteriorate and much of the soil strength is lost.

Measurements of change in strength of roots remaining in the soil after logging at Staney Creek on Prince of Wales Island, southeast Alaska, indicate that loss of strength in smaller roots occurs rapidly for all species the first 2 years. Western hemlock *(Tsuga heterophylla* (Raf.) Sarg.) roots are more resistant to loss of strength than are Sitka spruce *(Picea sitchensis* (Bong.) Carr.) roots. By 10 years, even the largest roots have lost appreciable strength.

KEYWORDS: Root morphology, root damage, soil stability, logging (-forest damage, Alaska (southeast).

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INTRODUCTION

A crucial factor in the stability of steep forested slopes is the role of plant roots in maintaining the shear strength of soil mantles. Roots add strength to the soil by vertically anchoring through the soil mass into fractures in the bedrock and by laterally tying the slope together across zones of weakness or instability.

In Japan, Endo and Tsuruta (1969) reported that soil shear strength increases in proportion to the amount of roots in the soil. Kitamura and Namba (1966, 1968) noted that the resistance of tree stumps to uprooting decreases rapidly as the root systems decay following timber harvest. They concluded, when considering root growth of planted trees, that the forest soil would reach a minimum strength between 5 and 10 years after cutting and replanting.

Bishop and Stevens (1964) and Swanston (1967, 1969) demonstrated the probable effect of roots on the stability of slopes in southeast Alaska and correlated increased landslide activity with time after logging. Wu (1976) measured the contribution of root tensile strength to shear strength of Karta soils at Hollis, Prince of Wales Island, and found it equivalent to at least a cohesion of 120 pounds per square inch (8.44 kg/cm^2) or about 25 percent of the total soil strength available to resist failure. Preliminary measurements of loss in root strength of both Sika spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) by simple penetration tests further indicate a maximum loss of root strength is attained 3 to 5 years after cutting (Swanston 1970).

Similar rates of strength loss are reported for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) roots in coastal British Columbia (O'Louglin 1974) and in the Oregon Coast Ranges (Burroughs and Thomas 1977). The senior author measured the influence of roots on in-situ shear strength in the Oregon-northern California coastal province and found that the reinforcing effect of the root mass significantly strengthened the soil.

The present study was initiated to quantify these relationships for southeast Alaska and to extend the data base of a much larger investigation to evaluate the interactions of root strength, root biomass, and soil strength in natural forest stands and the influence of logging on these factors. The larger investigation is a portion of a west-wide cooperative inter-Station research program to study mass wasting process and the influence of forest operations on slope stability.

METHODS

Sampling

A prime objective of this study was to measure the change in strength of roots remaining in the soil after logging. To keep the influence of other variables at a minimum, we selected sites having a wide range of cutting ages concentrated within a small geographic area. Staney Creek is one of the very few locations in southeast Alaska having such a wide diversity of cutting ages with

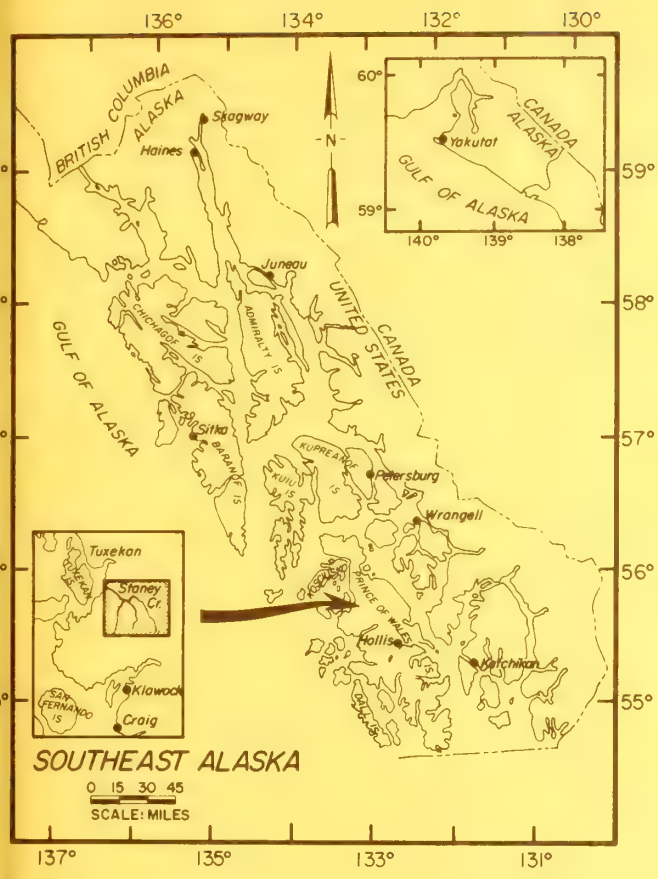

Figure 1.--Planimetric map of southeast Alaska showing location of the Staney Creek study site on the west coast of Prince of Wales Island. (For kilometers, multiply the number of miles by 1.609.)

similar environmental characteristics (fig. 1).

Within the Staney Creek area, five comparable sites, on which the trees had been cut in 1966, 1970, 1972, and 1974, and an uncut stand were found. Within each of the five sites, a western hemlock and a Sitka spruce tree or stump was selected for study. Live huckleberry (*Vaccinium parvifolium* Sm.) roots were also sampled in the clearcut units. Root samples were collected from the subsurface mineral soil rather than from within the extensive surface organic layer.

We planned to collect 15 separate root segments approximately 12 centimeters long for each of the six diameter classes for each species. These were 2-, 5-, 10-, 17-, 25-, and 50-millimeters inside the bark. We were unable to obtain the desired number of roots for some of the large size classes; and, in the areas cut in 1966 and 1970, root decay was so advanced that dead roots in the smaller size classes could not be found.

The selected roots were immediately packed in wet sphagnum, sealed in plastic bags, and air mailed to the laboratory in Arcata, California. At the laboratory, the roots were inventoried and stored at 2°C. Within 2 weeks, the roots were tested in the shear apparatus.

The results reported here represent data collected from a small geographic area. The slopes were limited to gentle terrain that was characteristic of the Staney Creek area but not generally characteristic of southeastern Alaska. The data are further limited to one tree per species in each of the five cutting age classes selected.

Shearing

Ten of the roots, if available, were prepared for shearing by removing the bark and marking each root into five equally spaced segments. The separation between segments was at least twice the root diameter to prevent one break from influencing subsequent tests. For large roots, only one or two breaks per root sample was possible. The minimum and maximum diameters of each segment were measured. Each root was then sheared at each segment mark.

The shear apparatus (fig. 2) consists of a stationary steel block machined to allow the insertion of hardened steel dies.[2/] A hole was drilled in the die to hold a root for each diameter class. A root having a diameter approximately equal to that of the hole was inserted through the die; it protruded at both sides. A movable steel block with a hardened steel V-shaped blade was machined to slide along the surface of the stationary block. The movable block was pushed by a mechanical jack until the protruding root segment failed.

The moving friction of the shear block and the maximum stress applied to each root segment at failure was measured by means of a proving ring and dial gage. Stress was applied to the root at a rate of 3.5 centimeters per minute. Both the moving friction and the maximum stress at failure were converted to kilograms of force.[3/] The net maximum stress (shear strength) was obtained by subtraction of the moving friction component from the maximum shearing force component.

In an earlier study, such direct shear strength measurements were found to give an excellent prediction of root tensile strength measured independently with an apparatus designed by Burroughs and Thomas (see footnote 2). A linear regression on paired breaks of the same root yielded the equation:

$$\text{Tensile strength} = -7.555 + 2.227\ (\text{Shear strength})$$

where, the root strengths were expressed in kilograms and the root diameters ranged from 1 to 10 millimeters. The explained variance (r^2) was 0.972. The direct shear strength measurements were preferred in our study because many more and larger roots could be tested in the limited time available.

[2/] Ziemer, R. R. An apparatus to measure the strength of roots. Unpublished report on file at Pacific Southwest Forest and Range Experiment Station, Arcata, Calif.

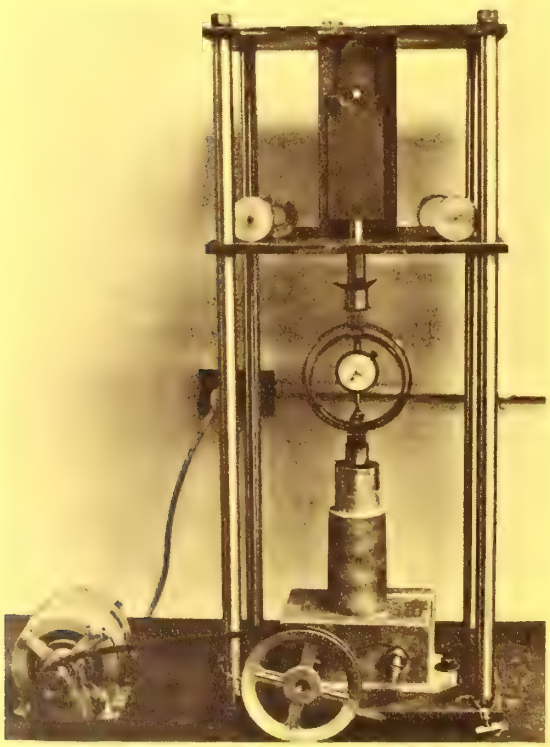

Figure 2.--Root shearing apparatus.

[3/] Here we follow the common engineering practice of expressing force in units of mass. Force is correctly expressed in units of mass-length/time^2 or in newtons. To convert: Newtons = mass (kg) X 9.807 m/sec^2 (gravitational acceleration). We further define the shear strength as the maximum shearing force applied at failure.

Tensile strength measurements are generally limited to roots less than 10 millimeters in diameter.

Physical and strength characteristics of each root segment were coded for subsequent analysis. The data were initially screened for anomalies such as cracked or dried roots, instrument malfunction, and observer errors. Such data were rejected from subsequent compilation.

The mean shear strength, standard deviation, and number of breaks were calculated for each species, age, and size class (table 1). Further statistical analysis of these data was not justified because the samples were, in no sense, collected at random.

RESULTS

During excavation, tree roots were found to range from resinous roots with a high resistance to decay to nonresinous roots that decayed rapidly. In companion studies, the senior author has observed similar decay resistant roots in coastal Oregon, the Oregon Cascades, and in coast redwood *(Sequoia sempervirens* (D. Don.) Endl.) stands and interior Douglas-fir stands of the northern California Coast Ranges. In the Sierra Nevada and southern California there is such heavy resin in pine roots infected with *Fomes annosus* that larger roots (100- to 200-mm diameter) have not deteriorated, even after 50 years.[4/]

[4/] Robert Bega, Plant Pathologist, Forest Disease Research, Pacific Southwest Forest and Range Experiment Station, Berkeley, California, personal correspondence, August 2, 1976. On file at Redwood Sciences Laboratory, Arcata, California.

Table 1--*Root strength of western hemlock, Sitka spruce, and huckleberry, by size class and time since logging*

Root diameter	Statistical measure[1/]	Live roots			Dead roots							
					Years since logging							
					2		4		6		10	
		Huckleberry	Western hemlock	Sitka spruce	Western hemlock	Sitka spruce	Western hemlock	Sitka spruce	Western hemlock	Sitka spruce	Western hemlock	Sitka spruce
mm												
2	$\bar{X}$	3.58	9.72	5.95	5.68	2.55	4.00	4.85	2.77	3.44	3.26	--
	σ	1.80	3.06	.60	1.41	.83	2.11	3.19	2.19	.90	2.02	--
	n	50.	50.	45.	50.	50.	45.	50.	50.	20.	20.	--
5	$\bar{X}$	30.38	42.73	25.35	28.09	20.44	21.87	38.42	21.48	13.09	17.96	13.10
	σ	8.28	11.63	7.54	7.02	7.79	9.53	16.23	11.58	2.17	5.18	6.72
	n	50.	50.	50.	50.	50.	55.	50.	50.	50.	50.	14.
10	$\bar{X}$	146.91	128.98	106.11	101.41	70.54	78.16	99.09	157.28	87.90	68.29	50.50
	σ	30.37	40.63	45.41	32.47	25.03	18.57	51.80	50.41	39.02	37.56	30.31
	n	44.	50.	49.	50.	50.	50.	49.	47.	49.	50.	47.
17	$\bar{X}$	442.5	454.4	501.4	318.6	149.4	255.6	319.0	551.2	303.1	409.6	153.9
	σ	194.8	120.5	164.9	193.8	23.0	74.6	162.5	130.2	141.3	181.5	82.6
	n	23.	36.	27.	50.	30.	30.	46.	48.	49.	45.	35.
25	$\bar{X}$	--	757.8	811.2	518.0	420.6	707.7	937.8	800.9	530.4	507.9	438.7
	σ	--	194.1	337.4	190.8	104.4	290.5	294.6	207.8	145.6	170.8	176.8
	n	--	23.	23.	32.	30.	37.	19.	49.	39.	46.	24.
50	$\bar{X}$	--	2884.	2427.	2806.	2257.	2581.	2705.	2984.	2608.	1391.	314.
	σ	--	124.	588.	265.	556.	679.	174.	80.	273.	387.	177.
	n	--	10.	10.	14.	5.	8.	7.	6.	11.	8.	6.

[1/] $\bar{X}$ = mean shear strength in kilograms; σ = standard deviation in kilograms; n = number of breaks.

LIVE ROOTS

There is a linear relationship between the logarithm of root strength and the logarithm of root diameter for live roots of the three southeast Alaska species tested (fig. 3).

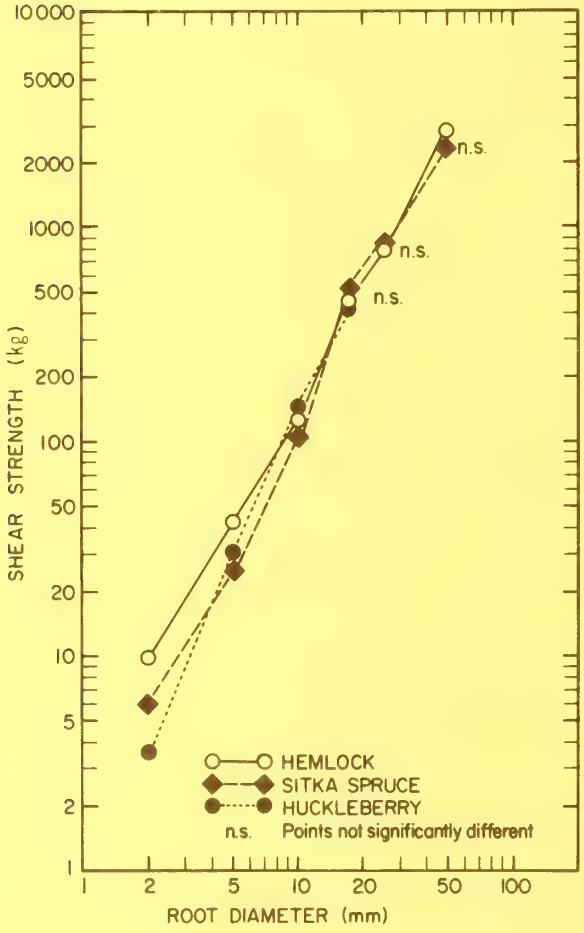

Figure 3.--Root shear strength vs. root diameter for live western hemlock, Sitka spruce, and huckleberry.

Sitka spruce roots are weaker than hemlock roots (fig. 3, table 1), particularly the smaller roots. For example, Sitka spruce roots, 2 to 5 mm in diameter, are about 40 percent weaker than similar size hemlock roots. This difference is less in 10-mm Sitka spruce roots, which are about 18 percent weaker than 10-mm hemlock roots. There is little difference in strength of live roots larger than 17 mm.

After logging, red huckleberry commonly invades the site. Very small huckleberry roots have substantially less strength than either hemlock or Sitka spruce roots of comparable size. For example, 2-mm roots of huckleberry are about 63 percent weaker than hemlock roots and about 40 percent weaker than Sitka spruce roots. This difference vanishes in roots with larger diameters, and there is little difference between the three species at 17 mm.

DEAD ROOTS

The contribution of tree roots to the strength of the soil is a function of the individual root strengths and the number of roots per unit volume of soil. Within the first few years after logging, there is a decrease in the average strength of the roots in the soil (fig. 4). Then, 4 to 6 years after logging, the strength of residual roots is at least as great as the average strength of live roots. By this time, however, most of the nonresinous roots have completely decayed and only resinous roots in the residual root biomass are left. Resinous roots are only a small fraction of the total root mass in the original live forest stand.

Several important differences between hemlock and Sitka spruce roots are related to size and change in strength with time after cutting.

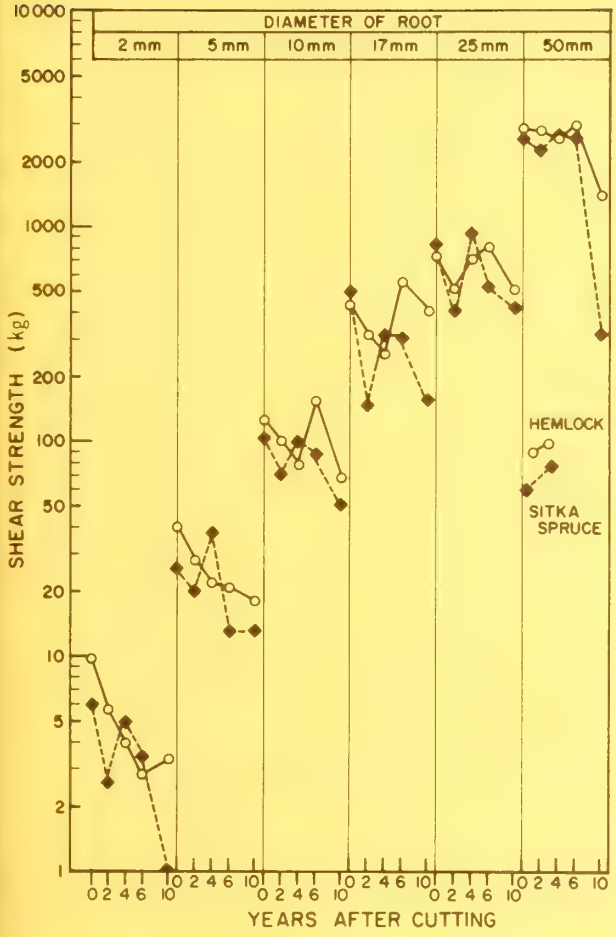

Figure 4.--Change in root shear strength, in years after cutting, for different root diameters of western hemlock and Sitka spruce.

Hemlock Roots

There is a continual loss in average strength of residual hemlock roots less than 25 mm in diameter with time after logging with about 32 percent of the strength lost during the first 2 years (Table 1, fig. 4). For example, for 2-mm diameter roots, there is a 42-percent loss in strength the first 2 years after logging. Within 4 years, there is a 59-percent loss. By 6 years, 70 percent of the strength of the residual roots is lost. Residual roots having a diameter of 5 mm show a 34-percent loss in strength the first 2 years. Within 4 years, half the strength is lost. By 10 years after cutting, 58 percent is lost.

A reduction in residual strength of intermediate size hemlock roots (10-25 mm) during the first 4 years after logging is followed by an apparent increase in strength as a result of dominance of resinous roots in the residual biomass. This increase reaches a peak about 6 years after cutting, then declines as the resinous roots begin to decay. The root strength at 6 years is at least as great as that of the original live roots. This does not imply that the strength of the soil-root matrix is increasing, because the total number of roots continually becomes smaller and the roots remaining in the soil are the decay resistant resinous roots which represent a small fraction of the original root biomass. By 10 years after cutting, even these resinous roots have begun to lose their strength.

There is no loss in strength of large hemlock roots (50 mm) during the first 6 years after cutting. Within the next 4 years, however, 50 percent of the strength is lost.

Sitka Spruce Roots

There is a decrease of about 50 percent in strength of Sitka spruce roots less than 25 mm in diameter within the first 2 years after logging, followed by an increase in the 4th year to a strength approximating that of live roots. This apparent increase is also due to the dominance of resinous roots in the biomass. After this 4-year peak, there is a continual

reduction in root strength as the resinous roots decay. By the 10th year, no roots less than 2 mm in diameter remain in the soil and few roots smaller than 5 mm. Therefore, essentially all strength from these smaller roots is gone. The remaining resinous roots, from 10 to 25 mm in diameter, lose about 50 percent of their strength between the 4th and 10th year.

There is no loss in strength of 50-mm roots for the first 6 years, but between 6 and 10 years, these large roots lose 87 percent of their strength.

Comparison of Roots of Hemlock and Sitka Spruce

In general, there were fewer residual Sitka spruce roots per age class, which suggested that they are less resistant to decay. Because the nonresinous fraction of the Sitka spruce roots decays more rapidly than the resinous fraction, the resinous roots dominate the residual biomass 2 years earlier than do the resinous roots of hemlock. As the proportion of nondecayed resinous roots rises, the average residual strength also rises. Therefore, this observed increase in strength of the Sitka spruce roots 4 years after logging and of the hemlock roots 6 years after logging reflects the rate of total decay of the nonresinous root fraction. This does not imply that the strength of the soil through the binding action of roots increases after logging since the total number of roots or biomass of roots continues to decline.

There appears to be no resinosis of hemlock roots less than 5 mm diameter, whereas resinosis is apparent in small Sitka spruce roots.

The average strength of residual Sitka spruce roots is consistently less than that of hemlock roots until 4 years after logging when the impact of resinosis is observed in Sitka spruce.

SUMMARY AND CONCLUSIONS

1. There is a linear relationship between the logarithm of root strength and the logarithm of root diameter for the live roots of Sitka spruce, western hemlock, and red huckleberry.

2. In uncut stands, hemlock roots are stronger than Sitka spruce roots.

3. Very small huckleberry roots have substantially less strength than either hemlock or Sitka spruce, but strength rapidly increases with diameter and closely approximates the strength of the tree roots above 10 mm diameter.

4. Sitka spruce roots decay more rapidly than do hemlock roots.

5. As tree roots decay with time after logging, residual hemlock roots continue to be stronger than residual Sitka spruce roots until 4 years after cutting.

6. Hemlock loses about one-third of the average strength of its roots smaller than 25 mm in diameter within 2 years after logging.

7. Sitka spruce loses about one-half the average strength of its roots smaller than 25 mm in diameter within 2 years after logging.

8. Within 2 years after logging, most of the original roots larger than 1 mm of the three species can still be found

in the soil. By 4 years, many of the roots have totally decayed, and a proportionately larger number of decay resistant, resinous roots are left. By 10 years after cutting, even these resinous roots have lost appreciable strength.

9. Since this study was exploratory and designed to provide data for a more regional evaluation of root strength, several limitations should be mentioned:

a. We studied a specific geographic area, namely Staney Creek, Prince of Wales Island.

b. We selected only one site for each age class.

c. We selected only one tree per species for each age class.

d. We located sites on relatively gentle terrain.

Subsequent studies and papers wil evaluate the significance of these factors on root strength and its rate of reduction after logging. A more definitive measure of the rate of root biomass loss after logging in southeast Alaska is also needed.

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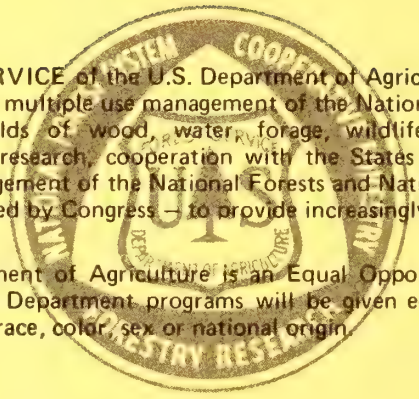

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COMPARISON OF SILVICULTURAL METHODS AT COYOTE CREEK WATERSHEDS IN SOUTHWESTERN OREGON--A CASE HISTORY

by

Don Minore, *Principal Plant Ecologist*,

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and

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ABSTRACT

Three similar southwestern Oregon watersheds, all having cool and moist climates, were logged by different methods in 1971. Five years after logging, regeneration was adequate on all three watersheds, but most abundant under a partially cut overstory. Tractor yarding compacted the subsoil, but seedling heights were similar on tractor and high-lead areas in 1976. Scarified, tractor-yarded areas regenerated most promptly.

KEYWORDS: Cutting systems (silvicultural), regeneration (natural), logging (-regeneration, watershed management, Oregon (Umpqua National Forest), Oregon (southwestern).

INTRODUCTION

Mixed conifer forests in southwestern Oregon contained approximately 10 percent of the Nation's softwood sawtimber in 1959 (Hayes 1959). Much of this timber has been cut since then, but the remaining old-growth forests constitute an extremely valuable resource. This uncut reservoir of old-growth timber will become progressively less important as logging operations continue, and southwestern Oregon's forest product industry will become increasingly dependent on the young forests that replace harvested old-growth stands. Unfortunately, prompt replacement of old-growth stands by vigorous young forests does not always occur. Hundreds of thousands of acres in southwestern Oregon do not support conifer stocking (MacLean 1976). Directly or indirectly, most of these unstocked acres are the result of logging operations.

Depending on the environment in which it is applied, a given timber harvesting technique may or may not create forest regeneration problems. Clearcutting is followed by abundant regeneration in some forest environments. In others, it creates conditions that make successful regeneration difficult. Similarly, removal of the old-growth overstory in several stages through partial cutting may be necessary in some environments but may complicate logging and hinder seedling growth in others.

Just as regeneration success varies with a given harvesting technique in different environments, so does it vary with different techniques in the same environment. It may not always be possible to identify optimal harvesting techniques in advance, but there are such techniques for every environmental situation. Yarding methods, size of cutting unit, and the amount of soil scarification and compaction are some of the variables that influence the establishment and growth of new stands in all environments. As part of a continuing effort to relate forest environments to harvesting techniques and subsequent forest regeneration in southwestern Oregon, the U.S. Forest Service is monitoring and comparing these variables on three adjacent experimental watersheds in the Umpqua National Forest.

STUDY AREA ENVIRONMENT

The three study watersheds are located in the South Umpqua River basin (T. 29 S, R. 1 E). They originally supported a mixed conifer forest containing approximately 50,000 board feet per acre (440 m^3/ha). Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Dougl.) Lindl.), incense-cedar (*Libocedrus decurrens* Torr.), and sugar pine (*Pinus lambertiana* Dougl.) predominated in the old growth. Occasional ponderosa pines (*Pinus ponderosa* Laws.) and western hemlocks (*Tsuga heterophylla* (Raf.) Sarg.) were also present. Occupying adjacent drainages (fig. 1), the three watersheds comprise 171, 169, and 123 acres (69.2, 68.2, and 49.8 ha). These Coyote Creek watersheds are referred to as CC-1, CC-2, and CC-3.

Elevations range from 2,300 to 3,500 feet (700 to 1 066 m) within the three watersheds. Slopes are gentle to moderate for the most part, with occasional steep pitches exceeding 50 percent. Soils are loams, silt loams, and silty clay loams, developed from

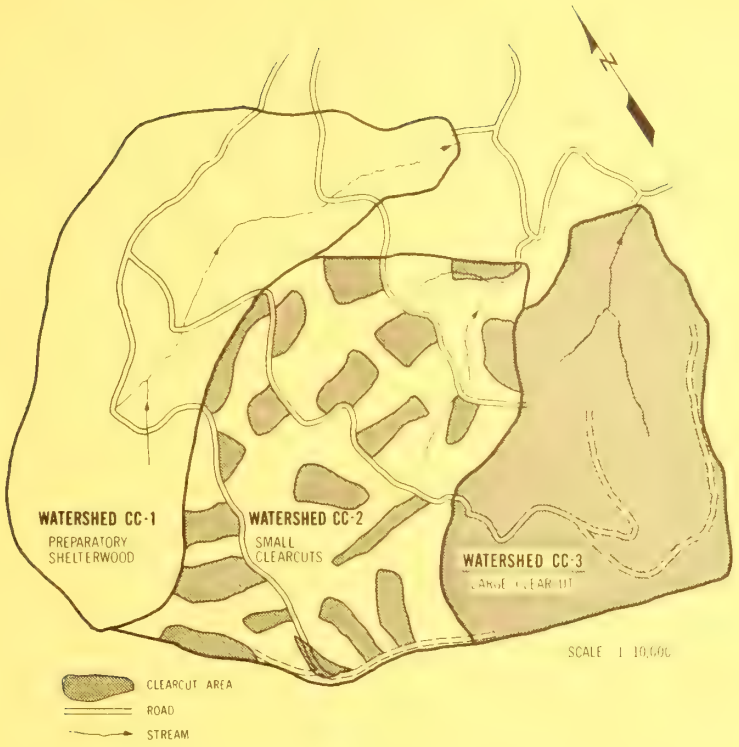

Figure 1.--Map of the three study watersheds, showing roads and cutting units.

reddish breccia and agglomerate parent materials throughout most of the area; clay loams and clays of basaltic origin occupy 5 to 10 percent of the watersheds (Richlen 1973).

In 1971, just before the watersheds were logged, 61 environmental classification plots were established at representative locations in the study area (14 plots in CC-1, 29 in CC-2, 18 in CC-3). Slope, aspect, soil depth (shallow or deep), soil texture, and vegetation were recorded at each location. Radiation, moisture, and temperature indices were then determined for each plot, and the plot environment was described according to the procedure outlined by Minore (1972). Future regeneration success after clearcutting was estimated by using the regression equations listed by Carkin and Minore (1974).

Radiation indices (values determined from slope and aspect measurements) measured on the environmental plots reflected the variety of slopes and aspects found within the study area. They ranged from 0.244 (low) to 0.569 (high). Soils sampled on the environmental plots were deep clay loams and silty clay loams for the most part (74 percent of the plots), but some deep loams (14 percent) and shallow, stony soils (12 percent) were also noted.

Plant species on the environmental plots (*Tsuga heterophylla*, *Clintonia uniflora*, *Anemone deltoidea*, and *Smilacina stellata*, for example) indicated moist conditions throughout the three watersheds. Although all three were moist by South Umpqua and southwestern Oregon standards, CC-3 (moisture index 11.5) was more moist than either CC-1 (moisture index 10.3) or CC-2

(moisture index 9.9). The majority of the environmental plot vegetation indices also indicated cool conditions. Only one-third of the area sampled was classified as "warm" or "hot" by the plant species occurring there. Temperature differences among the watersheds were small. CC-3 (temperature index 5.8) was cooler than either CC-1 (temperature index 6.2) or CC-2 (temperature index 6.9).

When measured elevation, radiation, moisture, and temperature indices were used to predict the future stocking of these areas after clearcutting, CC-3 (predicted stocking = 79 percent) appeared to be better suited to regeneration than CC-1 (predicted stocking = 74 percent) or CC-2 (predicted stocking = 65 percent).

SILVICULTURAL METHODS

All three watersheds were harvested during the summer of 1971, but different methods were used on each. A preparatory cut for creating a shelterwood stand was applied in one watershed (CC-1), clearcutting in the other two. Slash treatment varied, but no broadcast burning was done anywhere on the study area.

Cutting in CC-1 left an average residual overstory basal area of 155 ft^2/acre (6.2 m^2/ha) with a canopy density of 74 percent. Scarification by tractor yarding in this watershed removed the duff on half of the area creating a mineral soil seed bed. Slash was machine-piled and burned.

Twenty small units from 1.6 to 3.3 acres (0.65 to 1.34 ha) in size were clearcut on CC-2; 10 were tractor-yarded and 10 were high-lead yarded. Slash was machine-piled and burned on all the tractor-yarded units. Machine piling was also done on one high-lead unit; on the other nine, slash material more than 8 feet long and 8 inches in diameter (2.4 m long and 20 cm in diameter) was piled by high-lead (YUM[1/]-yarded). All landings were ripped after logging was completed.

CC-3 was clearcut as one large 123-acre (49.8-ha) unit (fig. 2). Both high-lead and

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1/ YUM = yarding unmerchantable material.

Figure 2.--Lower portion of CC-3 (clearcut in one large unit). May 1976.

tractor yarding were used. On portions of the area yarded by high-lead, cull logs were piled on landings. Where tractor yarding was used, slash was machine-piled and burned. The 10 landings used in logging this clearcut were ripped at the end of the operation.

REGENERATION AND SEEDLING GROWTH

Beginning in the spring of 1973, after the first postlogging growing season, regeneration was monitored annually by examining several hundred circular stocking plots. Exact numbers varied each year, but approximately 300 plots were examined in CC-1, 500-600 in CC-2 (25-30 per small clearcut), and 100 in CC-3. The plots were located mechanically in all three watersheds by pacing off uniform distances along evenly spaced compass lines. These compass lines ran across the areas sampled for environmental classification before logging. The same areas were sampled each spring. Remeasurement of identical individual plots was not attempted. Seedlings were counted by species on each 1/250-acre (0.001 6-ha) stocking plot during the first two surveys. After 1974, plot size was reduced to 1/300 acre (0.001 3-ha), and height measurements (the tallest seedlings of each species present) were substituted for seedling counts. A plot was considered scarified if at least half of its area was occupied by mineral soil. Four stocking surveys were completed--one after each growing season. We recorded supplemental measurements of overstory basal area and canopy density in CC-1 in 1976 by using a 10-factor prism and spherical densiometer. Soil bulk density was also measured in all three watersheds during the 1976 survey. Soil macropore space was measured with an air permeameter at several points.

The large clearcut (CC-3) was planted to Douglas-fir before the 1973 growing season. Seven of the small high-lead clearcuts in CC-2 were planted before the 1974 season. Unfortunately, the planting stock used in these areas was in poor condition when planted. Survival of this planted nursery stock was very poor: few planted seedlings were alive after the 1975 growing season. As a result, the stocking percentages measured in the 1973-75 surveys included some planted seedlings, but none are included in the most recent (1976) data.

Because the environmental measurements and stocking predictions indicated favorable conditions for regeneration in all three watersheds, we anticipated successful regeneration. After considering the area in its entirety, we concluded that successful regeneration did occur. There were noteworthy differences in regeneration rate within the study area, however--differences apparently related to harvesting methods (fig. 3). Following a heavy seed crop in 1972, CC-1 and CC-2 promptly regenerated wherever tractor yarding was used--adequate natural regeneration was present in the partially cut stand and in the small tractor-logged clearcut units after the first growing season (table 1.) High-lead units in CC-2 and the large clearcut in CC-3 were slower to regenerate. Scarified areas regenerated sooner than unscarified areas in all three watersheds, regardless of cutting or yarding methods used.

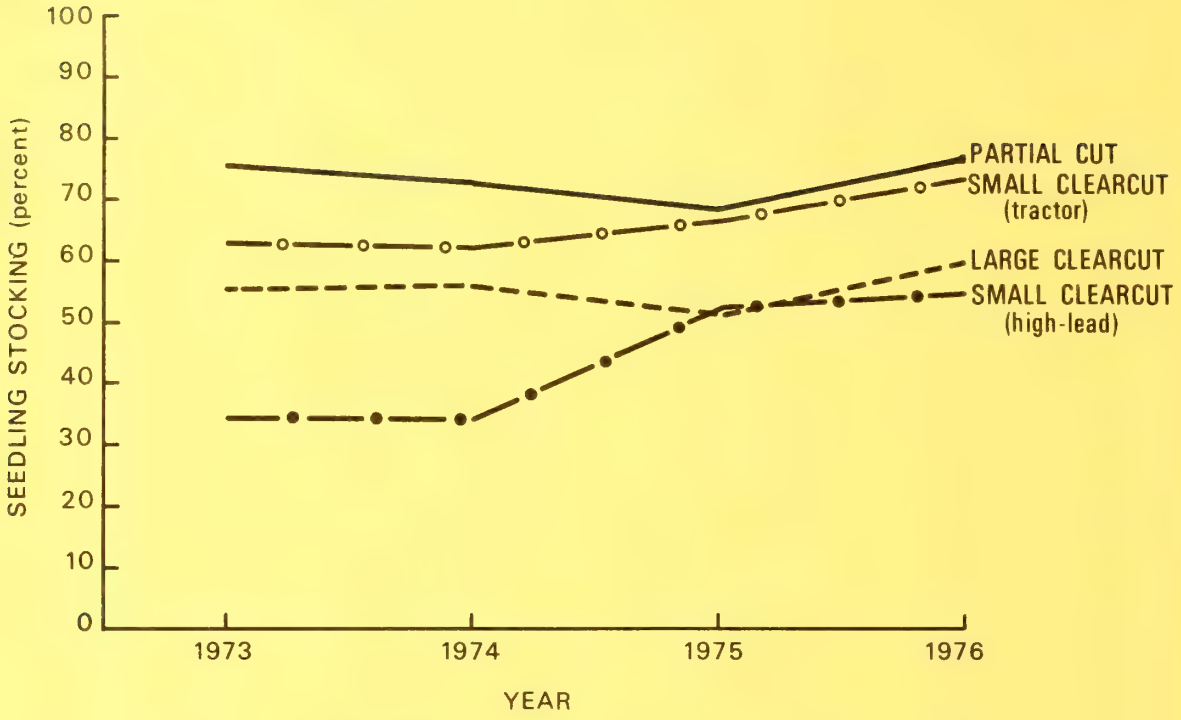

Figure 3.--Stocking of the tree seedlings, by year and harvesting method.

Table 1--*Average number of seedlings per acre*[1] *on three southwestern Oregon watersheds, by species, year, and seed bed*

Watershed and seed bed	Douglas-fir[2]		Incense-cedar		Grand fir		Sugar pine		Ponderosa pine		Western hemlock		All species	
	1973	1974	1973	1974	1973	1974	1973	1974	1973	1974	1973	1974	1973	1974
CC-1 (partial cut):														
Scarified	5,940	14,683	181	1,422	77	1,388	133	608	4	242	0	30	6,335	18,373
Unscarified	1,107	1,857	46	218	149	134	90	107	6	6	6	3	1,403	2,325
Burned	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All seed beds	2,659	5,545	89	564	126	495	104	251	5	74	4	11	2,987	6,940
CC-2 (small clearcuts):														
Scarified	2,486	2,713	403	515	8	138	33	31	0	46	0	13	2,929	3,458
Unscarified	464	716	60	126	13	27	24	37	0	6	0	1	561	913
Burned	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All seed beds	1,372	1,713	214	320	11	83	28	34	0	26	0	7	1,626	2,183
CC-3 (large clearcuts):														
Scarified	365	895	94	169	0	29	302	23	0	221	0	0	760	1,337
Unscarified	243	191	67	22	45	22	41	7	0	22	11	0	407	265
Burned	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All seed beds	275	536	74	95	33	24	110	15	0	122	8	0	500	792
All watersheds combined:														
Scarified	2,936	4,449	345	625	10	328	68	123	1	96	0	14	3,369	5,635
Unscarified	593	1,054	57	149	50	62	42	58	1	7	3	1	748	1,331
Burned	0	0	0	0	0	0	0	0	0	0	0	0	0	0
All seed beds	1,538	2,565	173	361	38	180	53	87	1	47	2	7	1,804	3,247

[1] For number of seedlings per hectare, multiply by 0.405.

[2] The present USDA Forest Service (Region 6) standard for 100-percent stocking in Douglas-fir is 450 well-established seedlings per acre.

Table 2--*Average regeneration stocking on three southwestern Oregon watersheds, by species and seed bed, May 1976*

Watershed and seed bed	Douglas-fir	Incense-cedar	Grand fir	Sugar pine	Ponderosa pine	Western hemlock	All species
				Percent			
CC-1 (partial cut):							
Scarified	65.4	4.8	3.7	9.6	4.8	1.1	89.4
Unscarified	41.3	5.4	10.9	7.6	0.5	0.5	66.2
Burned	0	0	0	0	0	0	0
All seed beds	53.1	5.1	7.2	8.5	2.7	.7	77.3
CC-2 (small clearcuts):							
Scarified	51.4	8.6	4.3	2.2	9.8	0	76.3
Unscarified	29.6	4.3	7.2	5.0	3.6	1.4	51.1
Burned	5.6	0	0	0	0	0	5.6
All seed beds	42.0	6.8	4.8	2.8	7.4	.4	64.2
CC-3 (large clearcuts):							
Scarified	38.8	2.0	0	0	28.6	0	69.4
Unscarified	34.9	2.3	9.3	2.3	7.0	0	55.8
Burned	25.0	0	0	0	0	0	25.0
All seed beds	36.5	2.1	4.2	1.0	17.7	0	61.5
All watersheds combined:							
Scarified	55.0	6.8	3.7	4.4	9.8	.4	80.1
Unscarified	36.1	4.6	9.3	6.0	2.5	.8	59.3
Burned	7.0	0	0	0	0	0	7.0
All seed beds	45.7	5.7	5.7	4.8	6.6	.5	69.0

Postharvest regeneration in the partial cut, CC-1, was more abundant than in either clearcut watershed in 1976 (table 2). Surprisingly, regeneration stocking in the large, 123-acre (49.8-ha) clearcut, CC-3, was only slightly poorer than the average stocking on the 20 small clearcut units in CC-2. Scarified areas had more abundant regeneration than unscarified areas in CC-1 and CC-2, but burned spots had less. Regeneration was abundant on the ripped landings in clearcut areas (fig. 4).

Scarification also benefited the seedling height growth of Douglas-fir in the clearcut areas (table 3). Stocking percent and seedling height growth did not vary consistently with variations in overstory basal area or canopy

Figure 4.--Abundant natural regeneration present on ripped landing in clearcut area. May 1976.

Table 3--*Average tallest seedling heights on three southwestern Oregon watersheds, by species and seed bed, May 1976*

Watershed and seed bed[1/]	Douglas-fir	Incense-cedar	Grand fir	Sugar pine	Ponderosa pine	Western hemlock	All species
				Centimeters			
CC-1 (partial cut):							
Scarified	27.4	19.9	23.2	20.1	28.0	24.5	24.4
Unscarified	21.6	22.8	20.0	18.6	20.0	35.0	21.0
All seed beds	25.8	20.4	22.2	19.8	27.6	29.8	23.6
CC-2 (small clearcuts):							
Scarified	33.1	29.0	28.0	25.7	36.3	21.0	31.5
Unscarified	31.9	31.5	29.3	38.9	42.5	13.0	33.0
All seed beds	32.9	29.3	28.2	30.8	36.8	19.4	31.8
CC-3 (large clearcuts):							
Scarified	39.0	32.6	26.0	29.7	47.8	--	40.6
Unscarified	44.5	--	42.7	14.0	50.0	--	42.5
All seed beds	40.3	32.6	36.0	25.8	48.2	--	41.2
All watersheds combined:							
Scarified	31.4	26.2	26.5	21.7	37.3	22.2	29.6
Unscarified	28.6	28.1	23.3	28.2	43.3	27.7	28.8
All seed beds	30.8	26.5	26.4	23.2	37.7	24.0	29.4
Number of seedlings	543	174	117	107	97	9	1,047

[1/] Burned seed beds have been omitted since only 3 seedlings occurred.

density in CC-1. However, seedlings of all species were shorter under the overstory canopy of CC-1 than they were in the clearcuts of CC-2 and CC-3. When all seed beds and all watersheds were considered, we found that ponderosa pine and Douglas-fir were taller than incense-cedar, grand fir, sugar pine, and western hemlock. Douglas-fir accounted for most of the stocking.

Tractor and high-lead yarding effects in the small clearcuts of CC-2 are compared in the following tabulation:

Effect	Tractor units	High-lead units
Average area scarified (percent)	90.4	39.6
Average stocking (percent)	73.6	54.8
Average seedling height (centimeters):		
Douglas-fir	34.0	31.2
Incense-cedar	30.3	26.0
Grand fir	28.1	28.4
Sugar pine	25.5	34.7
Ponderosa pine	35.8	38.8
All species	32.1	31.2

More than twice as much area was scarified by tractor yarding, and natural regeneration was better on the tractor units than it was on high-lead units (figs. 5 and 6). Although the regeneration data were not tallied by yarding method on CC-3, stocking differences between areas where tractor and high-lead yarding occurred were very evident (figs. 7 and 8). Five years after clearcutting, regeneration was most abundant on tractor-yarded areas. Yarding method had little effect on seedling height growth (see tabulation).

Tractor yarding usually results in soil compaction, a condition which often reduces the growth of trees. To assess the influence of tractor yarding on soil compaction and seedling growth, we measured bulk density of the top 4 inches (10 cm) of soil, plus both total height and 1975 growth of an adjacent Douglas-fir seedling at each of 26 points. The points were located on a variety of sites in all three watersheds, from undisturbed forest floor to heavily used skid trails and ripped landings. Bulk densities

Figure 5.--Portion of a small tractor unit in CC-2. Much of the area was scarified; stocking is excellent. May 1976.

igure 6.--Portion of a small high-lead unit in CC-2. Much of the area was not scarified; stocking is poor. May 1976.

Figure 7.--Tractor-yarded portion of large clearcut in CC-3. Note sparse competing vegetation, absence of debris, and abundant natural vegetation. May 1976.

Figure 8.--High-lead yarded portion of large clearcut in CC-3, approximately 150 feet (50 m) from area shown in figure 6. Note undisturbed vegetation, debris, and lack of regeneration. May 1976.

were low in all measurements--from 0.64 on one undisturbed area to 1.21 on a skid road (table 4).

Tractor yarding increased surface-soil bulk density somewhat in the study watersheds, but this increased density scarcely affected seedling growth during the first four growing seasons after logging. This lack of effect on growth may be misleading. Surface soils are readily loosened by frost heaving and biological activity, but materials deeper than 4 inches (10 cm) remain compacted for many years. Seedlings that grow well in the loosened surface soil may lack rooting space when they become saplings or poles. This compacted soil condition, observed to persist as long as 55 years (Power 1974), is indicated by the bulk density and air permeability measurements taken on tractor logged areas within the watersheds.

Table 4--*Average soil compaction and seedling height growth on three southwestern Oregon watersheds*

Area	Bulk density[2/]	Macropore space			Seedling height growth[3/]
		Soil depth, 2.5 cm	Soil depth, 15 cm	Soil depth, 30.0 cm	
	Grams/cubic centimeter	- - - - - - - - Percent - - - - - - - -			Centimeters
Tractor logged[1/]	0.99	21	10	10	7.8
Undisturbed	0.88	34	31	25	10.4

[1/] Includes tractor roads and tractor-piled areas.

[2/] Measured from the top 4 inches (10 cm) of soil.

[3/] Douglas-fir seedling height growth in 1975.

CONCLUSIONS

The three watersheds studied constitute moist, cool environments favorable for regeneration--regardless of the harvesting methods used in removing the old-growth stand. Data and conclusions derived from these watersheds, though not appliable in the warm, dry conditions found in much of the South Umpqua River basin, have important implications for the future management of similar environments. The increased stocking obtained after the preparatory shelterwood cut does not seem to be worth the increased logging effort and decreased seedling growth rates involved. If shelterwood cutting is applied in similar environments, soil scarification should increase both regeneration stocking and subsequent early seedling growth.

Clearcutting is probably the best harvesting method for moist, cool environments similar to those of the study watersheds. Large clearcut units like the one occupying CC-3, however, are less desirable than smaller units like those in CC-2. Environmental conditions on CC-3 were more favorable before harvesting than those on CC-2, yet regeneration was poorer. This may be attributed to the postharvest environmental differences associated with differing clearcut sizes on CC-2 and CC-3. Individual species stocking also varied with clearcut size (table 2). Ponderosa pine regenerated best in the large clearcut. Douglas-fir, incense-cedar, grand fir, and sugar pine were more successful in the small clearcuts.

In terms of initial regeneration success, tractor yarding was superior to high-lead yarding; however, the relatively small increases in surface soil bulk density and relatively large decreases in subsoil macropore space associated with tractor yarding may impede future seedling growth.

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USDA FOREST SERVICE RESEARCH NOTE

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AMMONIUM THIOCYANATE DOES NOT INCREASE HERBICIDAL CONTROL OF SALMONBERRY

by

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ABSTRACT

Addition of ammonium thiocyanate to sprays containing 2,4,5-T or silvex does not increase control of salmonberry shrubs compared to the two herbicides applied alone; both herbicides were more effective when applied in late spring than in midsummer. Ammonium thiocyanate markedly improved degree of salmonberry control obtained with amitrole.

KEYWORDS: Herbicides (-forest weed control, brush control, salmonberry, ammonium thiocyanate.

INTRODUCTION

Salmonberry *(Rubus spectabilis)* shrubs quickly occupy freshly burned or newly harvested areas of highly productive forest lands in the Coast Ranges of Oregon and Washington. If not controlled, salmonberry will form a dense canopy and reduce survival and growth of desirable conifer seedlings (Ruth 1956). Control sufficient to release established conifers can be obtained with foliage sprays of 2,4,5-T (2,4,5-trichlorophenoxy) acetic acid, silvex (2,4,5-trichlorophenoxy) propionic acid, or amitrole [3-amino-*s*-triazole](Gratkowski 1971, Krygier and Ruth 1961, Stewart 1974a). Amitrole-T, a 1:1 mixture of amitrole and ammonium thiocyanate [NH_4SCN], is also effective on salmonberry (Gratkowski 1971, Stewart 1974a).

Salmonberry shrubs resprout from roots and bases of stems following treatment with herbicides, and repeated spraying is necessary on some areas to prevent resprouting shrubs from again dominating the site. More effective herbicidal treatments are desired to reduce the need for respraying. Several studies have shown that ammonium thiocyanate at rates as low as 1/4 to 3/4 lb per acre (0.28 to 0.84 kg per ha) can enhance the effectiveness of phenoxy herbicides on rangeland shrubs (Basler et al. 1967, Elwell 1968, Robison 1965, Stritzke 1975). The study described here was designed to determine if addition of ammonium thiocyanate to 2,4,5-T, silvex, or amitrole would increase herbicidal effects on salmonberry.

MATERIALS AND METHODS

A previous study has shown that both late spring and midsummer foliage sprays are effective on salmonberry (Stewart 1974a). Therefore, 240 vigorous salmonberry shrubs 4 to 6 feet (1.2 to 1.8 m) high were selected in a 2-year-old clearcut near Lakeside, Oregon for treatment on May 19 (late spring) or July 25 (midsummer) in 1972. About three-quarters of the salmonberry crowns were fully developed when the shrubs were sprayed on May 19. By July 25 crowns were fully developed, active growth had stopped, and fruits had disseminated. On each date, 10 randomly selected shrubs were treated with one of the formulations shown in table 1. The study was installed as a 3 x 4 x 2 factorial design with 10 replications.

Table 1--*Herbicidal treatments evaluated as late spring and midsummer sprays on salmonberry*

Herbicide and rate (aehg)[1/]	Amount of NH_4SCN added
	lb aihg[2/]
None	0
	1/4
	3/4
1 lb 2,4,5-T as butoxyethanol esters	0
	1/4
	3/4
1 lb silvex as butoxyethanol esters	0
	1/4
	3/4
1 lb[2/] amitrole as a water soluble liquid	0
	1/4
	3/4

[1/] Pounds of acid equivalent per 100 gallons of total spray mixture (1 lb is equivalent to 0.45 kg).

[2/] Pounds of active ingredient per 100 gallons of total spray mixture (1 lb/gal is equivalent to 0.12 kg per liter).

Herbicides were applied to drip point on the foliage of each plant using knapsack sprayers. All sprays, except for those containing amitrole, were applied in a 3-percent diesel oil-in-water emulsion carrier; amitrol was applied in water. A special emulsion system containing all additives found in a commercial butoxyethanol ester formulation of 2,4,5-T was used to form the emulsion for ammonium thiocyanate applied without herbicides. In order to measure differences due to addition of ammonium thiocyanate, herbicidal dosages used were one-third the optimum level for best control (Stewart 1974a).

Topkill, number of plants killed (complete topkill with no resprouting), and number and height of basal or root sprouts were observed in August of 1973, 13 to 15 months after sprays were applied. Topkill and number and height of sprouts were analyzed by analysis of variance and treatment differences were compared using sets of orthogonal contrasts. A chi-square test for homogeneity of variance indicated that the herbicides were operating as unrelated populations. Therefore, herbicides were analyzed separately. Because of the small number of plants killed at the herbicidal dosages used, plant kill could not be analyzed. Treatment differences were tested at the 5-percent level of probability.

RESULTS AND DISCUSSION

Addition of 1/4- or 3/4-lb aihg of ammonium thiocyanate to 2,4,5-T, silvex, or amitrole did not increase degree of topkill or reduce number and size of sprouts (table 2). This lack of response was more evident for the two phenoxy herbicides than for amitrole. Of course, the high degree of topkill obtained with the phenoxy herbicides without ammonium thiocyanate leaves little room for improvement. For late spring sprays of amitrole, average topkill of salmonberry shrubs increased with addition of ammonium thiocyanate. This increase was not statistically significant, however, due to variability in degree of control on individual plants. This variability has also been observed with amitrole-T (Stewart 1974a), and results from repeated sprays (Stewart 1974b) suggest that this may arise from inherited resistance to amitrole in individual salmonberry plants and clones. Ammonium thiocyanate appeared to increase degree of plant kill obtained with amitrole. This result justifies the use of amitrole-T rather than amitrole for salmonberry control.

Late spring sprays of 2,4,5-T and silvex were more effective than midsummer sprays. In late spring, topkill was greater with 2,4,5-T and resprout control better with silvex. Applications made early in the growing season after about three-quarters of the salmonberry crown is fully developed have proved effective (Krygier and Ruth 1961, Stewart 1974a). Conifers, however, are more resistant to phenoxy herbicides applied in midsummer after buds have set. Therefore, midsummer sprays are preferred to release conifers despite reduced effects on salmonberry.

Table 2 --*Response of salmonberry to NH_4SCN alone and in mixture with 2,4,5-T, silvex, and amitrole applied as late spring or midsummer foliage sprays*

Herbicide	Amount of NH_4SCN	Late spring spray				Midsummer spray			
		Top-kill	Plant kill	Average number and height of sprouts		Top-kill	Plant kill	Average number and height of sprouts	
	lb aihg[1/]	- Percent -		Number	cm	- Percent -		Number	cm
None	0	4	0	0	0	4	0	0.4	12
	1/4	1	0	1.4	8	3	0	0	0
	3/4	4	0	0.3	16	13	0	1.1	8
2,4,5-T	0	98	0	6.8	57	90	0	5.8	72
	1/4	99	0	4.5	70	87	0	4.1	84
	3/4	100	40	4.0	70	92	0	7.4	72
Silvex	0	89	10	2.5	68	78	0	9.2	93
	1/4	100	10	3.8	68	96	0	8.4	79
	3/4	90	0	3.7	54	75	0	5.2	88
Amitrole	0	41	10	0.9	19	64	50	1.8	29
	1/4	70	20	1.2	37	50	30	0.7	22
	3/4	84	50	3.4	28	61	80	1.6	10

[1/] Pounds of active ingredient per 100 gallons of total spray mixture (1 lb/gal is equivalent to 0.12 kg per liter).

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Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key--out of the reach of children and animals--and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly. Spills of herbicides or spray adjuvants should immediately be cleaned from work surfaces and mixing platforms. Spray adjuvants such as Vistik, Dacagin, Norbak, and foaming agents are especially slippery and should be immediately flushed off with water.

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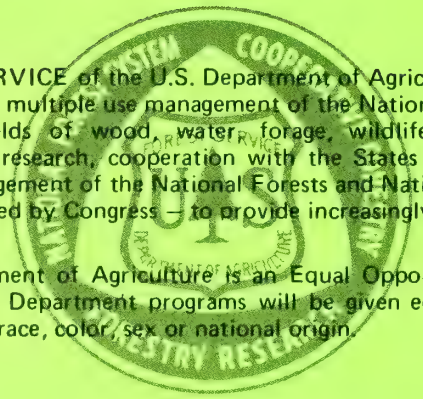

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USDA FOREST SERVICE RESEARCH NOTE

3.79: PNW-309

PNW-309 December 1977

ATRAZINE PROMOTES PONDEROSA PINE REGENERATION

Glenn L. Crouch and Erwin Hafenstein [1/]

ABSTRACT

Atrazine applied by helicopter improved survival of planted ponderosa pines (*Pinus ponderosa* Laws.) subjected to competition from herbaceous vegetation and to predation by pocket gophers. Atrazine also improved the seedling-establishment environment; seed fall from scattered overstory trees produced 45-percent stocking and more than 300 trees per acre (741/ha) 7 years after the herbicide was applied.

KEYWORDS: Herbicides (-natural regeneration, herbicides (-artificial regeneration, rodent control (forest), atrazine, gophers (pocket), ponderosa pine, *Pinus ponderosa*.

[1/] At the time this research was conducted, Glenn L. Crouch was principal plant ecologist at the Pacific Northwest Forest and Range Experiment Station. He is now principal research wildlife biologist at Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. Erwin Hafenstein is a forester at Winema National Forest, Klamath Falls, Oregon.

Pocket gophers (*Thomomys* spp.) hinder regeneration of logged and burned lands on many western forests[2/] (Crouch 1969, Barnes 1973).

Gophers feed on stems, roots, and, to a lesser extent, foliage of seedlings and saplings of most conifer species; their feeding usually results in mortality of the trees (Crouch 1971). These animals can destroy new plantations within a year of planting or may kill a portion of the trees annually for 10 years or more. In either case, stocking is reduced. When a portion of the trees are killed, many years of potential growth are lost and costly site preparation is often needed before replanting. Moreover, replanting may not be successful unless gopher damage is controlled.

For many years, damage by gophers has been controlled by poisoning the animals to reduce their numbers (Scheffer 1910, Crouch 1933, Barnes et al. 1970). Poisoning by hand or machine has reduced damage to many agricultural crops, but there is little documentation of successful protection of tree seedlings despite treatment of tens of thousands of acres with toxic baits. Trapping has also been used to reduce numbers of gophers, but most foresters believe it is logistically unsuitable and prohibitively expensive. In either case, problems inherent with effective treatment of vast acreages of wild land, year after year in some areas, are overwhelming. Clearly, a more effective technique is needed, one that is longer lasting and easier to apply.

In the 1950's Keith and others (1959) sprayed gopher-infested Colorado rangelands with 2,4-D and virtually eliminated forbs from a forb-grass vegetation complex. The next year numbers of gophers declined dramatically, apparently in response to the loss of their primary food supply. Declines in numbers of gophers after herbicide application were also noted by Howard and Childs (1959) and Hull (1971). Recently, Stewart and Beebe (1974) and Christensen and others (1974) reported improved survival of pine seedlings after treatment with atrazine.

In 1964, personnel of the Chiloquin Ranger District, Winema National Forest, treated small test plots of planted ponderosa pines (*Pinus ponderosa*)[3/] with several herbicides to reduce vegetative competition and gopher predation. The test area was located on the Cave Mountain Burn, near Chiloquin, Oregon, an area swept by wildfire in 1959, salvage-logged, and machine-planted with pines in the early 1960's. By 1964, because of gophers and other factors, the plantation was declared a failure (Barnes 1973).

Some of the tested herbicides killed trees; others, including atrazine, showed promise for promoting survival and growth. The study reported here, an expansion of the 1964 trial, was based on that work and on preliminary findings from a more complex study

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[2/] Northwest Forest Pocket Gopher Committee. 1976. Survey of pocket gopher damage to conifers in the Pacific Northwest 1975. (Mimeogr.) Oregon-Washington Silvicultural Council, Western Forestry and Conservation Association.

[3/] Plant names follow Hitchcock and Cronquist (1973).

begun by the senior author in 1966 on a nearby site.

STUDY AREA AND METHODS

The investigation was conducted as a U.S. Forest Service administrative study, following established guidelines, and was designed to test the efficacy of atrazine combined with seeding and planting to establish ponderosa pine. In addition, bitterbrush (*Purshia tridentata*) was seeded or planted with the pine in two treatments, because shrub-dominated communities in the area appeared to support few gophers, and trees growing there incurred little damage from those rodents.

The study area was 100 acres (40.5 ha) on pumice soil, in a relatively uniform ponderosa pine-bitterbrush-needlegrass (*Stipa occidentalis*) plant community (Volland 1976). By 1967 when the study was begun, the site was occupied by widely spaced, mature ponderosa pines, scattered remnants of earlier pine plantings, and a few natural seedlings. Occasional bitterbrush and currant shrubs (*Ribes cereum*) were present, but needlegrass was the predominant cover. Forbs were rare. Gopher mounds were abundant over the entire area, and the lack of pine regeneration was largely attributed to gophers.

The entire 100-acre (40.5-ha) area was sprayed by helicopter with atrazine at 4 pounds of active ingredient per acre (4.48 kg/ha) in November 1967. Twelve 1-acre (0.41-ha) treatment plots, separated by 150-foot (45.7-m) buffer strips, were then established in blocks of four plots each within the central, most uniform part of the sprayed area. The following treatments were applied randomly at one each per block:

T_1 - Seeded with bitterbrush at 3 pounds per acre (3.36 kg/ha) with a rangeland drill in November 1968; planted with 2-0 ponderosa pine at 680 per acre (1,680/ha) in April 1971.

T_2 - Planted with 2-0 bitterbrush at 2,000 per acre (4,942/ha) in June 1970; planted with 2-0 ponderosa pine at 680 per acre (1,680/ha) in May 1970 and replanted in April 1971.

T_3 - Seeded with endrin-treated ponderosa pine seed at 6 pounds per acre (6.72 kg/ha) in November 1968.

T_4 - One-half of each plot planted with 2-0 ponderosa pine at 680 per acre (1,680/ha) in May 1970, and the second half planted in April 1971.

Unfortunately, the original plan allowed comparisons only among seeding and planting treatments. No evaluation of atrazine effect was possible, nor could atrazine plus treatments be compared with plantings where no atrazine was applied. To provide more information, local foresters added two 1-acre treatment plots on an adjacent unsprayed site. These additions were planted with 2-0 pines in spring 1970 and 1971 at the time of the final applications of the four treatments.

The original plan called for a rudimentary evaluation of seeding and planting success each year for 5 years. Results from this evaluation, on file at the Chiloquin

Ranger Station, Chiloquin, Oregon, were inconclusive.

Findings reported here are derived from data collected in 1972 and 1975 from (1) the original treatment plots and one buffer strip randomly selected from each block (ATR), (2) the added plantings on plots not receiving atrazine, and (3) unsprayed-unplanted plots we selected as representing pre-treatment environments and stocking levels comparable to those in (1) and (2).

Effects of treatment on tree establishment were evaluated by counting trees in twenty 1/250-acre (1/618-ha) circular subplots in each treatment plot. Four lines of five subplots each, spaced 25 feet (7.6 m) apart were randomly distributed in each plot for sampling. Bitterbrush plants were also counted in the subplots.

DATA ANALYSIS

Data from atrazine treatments were subjected to analyses of variance with arc-sin transformations of percentage values. Then, orthogonal comparisons were made at $P = 0.05$ to further identify similarities and differences among treatments and groups of treatments.

Findings from planted plots not receiving atrazine and from untreated and unplanted plots could not be directly compared with herbicide seeded and planted combinations because they were not included in the original block design; however, these comparisons are vitally important to managers. Therefore, mean values of tree stocking and densities were determined for the added treatments, and confidence limits were calculated to provide a measure of comparability.

RESULTS AND DISCUSSION

Observations in the 1968 growing season indicated that atrazine applied the previous fall had greatly reduced herbaceous cover. Because the scattered pine overstory prevented complete aerial coverage of the study area, the unaffected acres were ground-sprayed in November 1968.

Mature trees on the site had an exceptionally large seed crop in 1968, and cursory examinations in spring and summer of 1969 revealed many germinating seeds and seedlings in all treatment plots.

We did not visit the area again until 1972. At that time, atrazine effects were still amply evident and pine seedlings were abundant over much of the sprayed area, even where there had been no other treatment.

Results of tree counts in 1972 and 1975 are shown in table 1. Analyses indicate that planted plots had significantly better stocking and more seedlings than those not planted. Moreover, plots planted twice (T_2) had significantly better stocking and more seedlings than those planted once (T_1) or planted half one year and half the next (T_4). Seeding (T_3) produced no more seedlings than were found in plots treated only with atrazine (ATR). Although stocking and seedling densities were lower in 1975 than 1972, the relative rankings among treatments did not change.

Table 1--*Mean stocking and density of ponderosa pines on the Cave Mountain Burn study area in Oregon*

Inspection date	Treatment[1/]				
	T_1	T_2	T_3	T_4	ATR
	STOCKING PERCENT				
1972	77	100	63	90	53
1975	67	96	42	84	45
	TREES PER ACRE[2/]				
1972	1,220	1,720	685	1,025	510
1975	940	1,375	320	955	310

[1/] T_1 = seeded with 3 lb bitterbrush per acre in November 1968; planted with 680 2-0 ponderosa pine per acre in April 1971. T_2 = planted with 2,000 2-0 bitterbrush per acre in June 1970; planted with 680 2-0 ponderosa pine per acre in May 1970 and replanted in April 1971. T_3 = seeded with 6 lb endrin-treated ponderosa pine seed per acre in November 1968. T_4 = one half of each plot planted with 680 2-0 ponderosa pine per acre in May 1970 and the second half planted in April 1971. ATR = treated only with atrazine.

[2/] Trees per acre times 2.471 equal trees per hectare.

Plots seeded or planted with bitterbrush (T_1 and T_2) averaged significantly greater stocking and numbers of shrubs than other treatments (table 2). Numbers of bitterbrush plants established were however, fewer than expected when the amount of seed drilled and numbers of seedlings planted are considered. By 1975, bitterbrush cover was too sparse to influence gophers or otherwise affect the pines.

Comparisons of unsprayed-unplanted, unsprayed-planted and sprayed-planted (T_2) plots are shown in table 3. It is clear that planted plots sprayed with atrazine had far greater stocking and many more seedlings. In fact, planting without atrazine appeared little better than no treatment by 1975.

Certainly, atrazine contributed greatly to the high numbers of seedlings found in sprayed plots, but it was not possible to determine if benefits resulted from reduction of plant competition, reduction of losses caused by gophers, or both. In 1975, about 7 percent of the seedlings present on all plots had been recently killed by gophers. Although unlikely, should this rate of loss persist without additional recruitment of trees, few will survive to produce harvestable products, especially on poorly stocked plots.

Table 2--*Mean stocking and density of bitterbrush on the Cave Mountain Burn study area in Oregon*

Inspection date	Treatment[1/]				
	T_1	T_2	T_3	T_4	ATR
	STOCKING PERCENT				
1972	53	63	11	7	2
1975	42	58	9	2	4
	SHRUBS PER ACRE[2/]				
1972	240	275	30	10	10
1975	140	200	20	5	10

[1/] T_1 = seeded with 3 lb bitterbrush per acre in November 1968; planted with 680 2-0 ponderosa pine per acre in April 1971. T_2 = planted with 2,000 2-0 bitterbrush per acre in June 1970; planted with 680 2-0 ponderosa pine per acre in May 1970 and replanted in April 1971. T_3 = seeded with 6 lb endrin-treated ponderosa pine seed per acre in November 1968. T_4 = one-half of each plot planted with 680 2-0 ponderosa pine per acre in May 1970 and the second half planted in April 1971. ATR = treated only with atrazine.

[2/] Trees per acre times 2.471 equal trees per hectare.

Table 3--*Mean stocking and density of ponderosa pines growing on unplanted and planted unsprayed plots and on planted plots sprayed with atrazine on the Cave Mountain Burn study area in Oregon*

Inspection date	Treatment		
	No atrazine, unplanted plots	No atrazine, planted plots	Atrazine, planted (T_2)[1/] plots
	STOCKING PERCENT		
1972	15 ± 12[2/]	55 ± 19	100 ± 0
1975	15 ± 12	37 ± 22	96 ± 8
	TREES PER ACRE[3/]		
1972	45 ± 35	280 ± 120	1,720 ± 560
1975	40 ± 30	120 ± 55	1,375 ± 380

[1/] T_2 = planted with 2,000 2-0 bitterbrush per acre in June 1970; planted with 680 2-0 ponderosa pine per acre in May 1970 and replanted in April 1971.

[2/] Confidence intervals equal $\bar{x} \pm t.05\ (S\bar{x})$.

[3/] Trees per acre times 2.471 equal trees per hectare.

Finally, 45-percent stocking and more than 300 trees per acre (741/ha) on plots treated only with atrazine suggest that herbicide treatment might be used to enhance success of natural regeneration in years of good seed crops in stands with cone-bearing trees but highly competitive understory vegetation.

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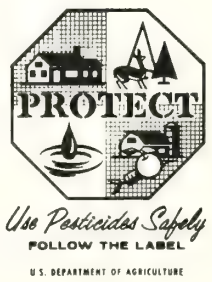

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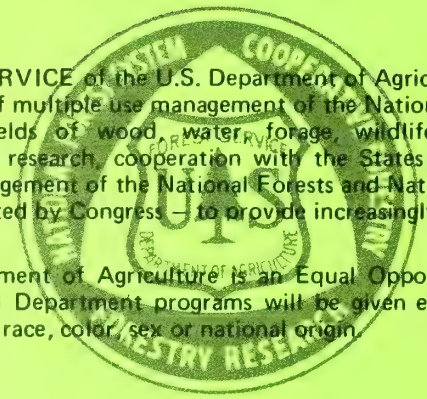

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-310

January 1978

PREPARING MANUSCRIPTS FOR PROCEEDINGS AND COMPENDIUMS

by

Tom Baugh,
Supervisory Technical Publications Editor

and

Betty Bell,
Editor, Printed Media

ABSTRACT

Proceedings and compendiums can be an efficient way of presenting a large amount of related research information. Both time and cost of production can be decreased if individual papers are prepared in the same format. This Research Note presents highlights of the format used by the Pacific Northwest Forest and Range Experiment Station.

KEYWORDS: Communications, conferences/meetings (technical/scientific).

INTRODUCTION

Proceedings and compendiums prepared by the Pacific Northwest Forest and Range Experiment Station (PNW Station) are published as General Technical Reports (GTR). These reports can be an efficient way of presenting a large amount of related research information.

The PNW Station is often faced with the task of editing, processing, and publishing compendiums and the proceedings of symposiums. Authors contributing manuscripts come from diverse employment backgrounds. They may be employed by Federal or State agencies, universities, or

private business concerns. In their various work environments contributing authors may be subject to a system of rigid editing or no editing; the format in which a manuscript is submitted to their own editors may be highly stylized or very lenient.

The publication of lengthy GTR's is time consuming and expensive. Both cost and time can be reduced if individual contributions are prepared in the same format. This Research Note presents the highlights of the format required by the PNW Station. Not all aspects of format are covered in this Note, only those which appear to give authors, and consequently editors, the greatest trouble. This note has a minimum of narrative. It begins by covering Station, agency, and Department regulations, followed by some specifics of required format. Each item is identified along the left margin.

Station scientists, acting as compilers of proceedings and compendiums, should insure that each contributing author receives a copy of this Note. PAPERS NOT PREPARED IN THIS FORMAT WILL BE RETURNED TO THE COMPILER.

In this Note, we do not discuss questions of grammar or other aspects of composition. Authors should present a concise, simply worded, properly written, and well-organized text. Authors should carefully question the need for each word, the structure of each sentence, the organization of each paragraph, and the communication efficiency of the final draft of the manuscript. Communication of concepts, ideas, and information is the most important function of any publication.

As editors, we will do everything possible to suggest how authors can improve the communication potential of their information; however, author must do their own rewriting.

We recommend the following sources as guidelines for grammar and composition. For quick reference to common problems, use Strunk and White (1972). For general aspects of technical writing, refer to Brusaw et al. (1976). A comprehensive treatment of English grammar is available from U.S. Department of the Treasury, Internal Revenue Service (1973). For accepted usage of the English language, consult Evan and Evans (1957).

Unless otherwise stated, all of the items in this Note must be performed before manuscripts are submitted to the PNW Station Editorial Group. Compilers should carefully read this Note before passing it on to contributing authors.

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Any PNW Station scientist considering taking leadership in compiling a proceedings must first have approval from the Station Director.

In addition, proposals for proceedings which are more than regional in scope must be offered to the Leader, Publications Group, Washington Office, on Publication Proposal Form 1600-6. The editor will show the compiler how this is handled.

The compiler is also responsible for submitting with the manuscript, a PNW Manuscript Approval Form (1600-1, rev. 2/76), which must be signed by the compiler, project leader, and assistant director.

LIST OF TITLES

The symposium coordinator is responsible for preparing a list of article titles, arranging the list in the order in which the articles are to appear in the proceedings, and sending the list to the Editorial Group. Each paper by a PNW Station author must be accompanied by a properly completed Manuscript Approval Form (PNW 1600-1, rev. 2/76).

STATISTICAL ANALYSIS

PNW Station policy requires that all manuscripts containing statistical analysis of any level must be reviewed by the Station Biometrician or another biometrician prior to editing. Statistical analysis specifically means that an analytical process, relying on the fundamentals of statistics and requiring inference, has been performed.

PERMISSIONS

The Forest Service Manual (FSM 1633.71, Feb. 75, Amend. 47) states: "Non-Government illustrations will be used only with permissions of the source. Permission must be obtained in writing in the case of copyrighted illustrations, ownership being indicated in a 'Courtesy of. . .' or copyright line. Avoid showing commercial names in published photographs, if possible."

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Authors and Station Project Leaders and Assistant Directors are responsible for acknowledging cooperation of other agencies or organizations.

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If naming of a company or product is necessary, at the first mention add a footnote, stating "The use of trade, firm, or corporation names does not constitute an official endorsement of or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable."

PESTICIDES

If a manuscript refers to pesticides, it must be approved by the Station Pesticide Use Coordinator. At the first mention of a pesticide add a footnote that says "Pesticides." (The editors will assign the proper pesticide statement after consulting with the Pesticide Use Coordinator.)

REFERENCE MATERIAL

The "U.S. Government Printing Office Style Manual" (U.S. Government Printing Office 1973) is our first source for form, including capitalization, spelling, compounding, punctuation, abbreviations, symbols, and numerals. "Council of Biology Editors Style Manual" (Council of Biology Editors, Committee on Form and Style 1972) is our second source. Agriculture Handbook 433, "Preparing Statistical Tables" (U.S. Department of Agriculture 1972), is a guide for table preparation. For literature citations refer to "Preparing Citations for USDA Forest Service Publications" (USDA Forest Service 1975).

SPACING

Double space EVERYTHING (no exceptions). Type only on one side of each page. Leave 1½-inch margins on both sides and at top and bottom. Submit only the ribbon copy of the manuscript. Manuscripts with any part single spaced will be returned for double spacing.

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Prepare title page this way:

1

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Select five words which best describe the subject of your paper.

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The author is responsible for assigning headings to various sections of his manuscript. Headings indicate the organization of a manuscript and help guide readers from general categories of information (first-grade heading) to increasingly specific categories (second-grade, third-grade). Headings are set up in the manuscript as follows:

(1st grade) BIG BUGS

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In addition to the headings in the paper, the author must also furnish a separate grade-heading list with the manuscript. The list should be set up as follows:

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Footnotes should appear between two lines following the line in which they first appear; the footnote number should be indented five spaces:

3/ Gross scale is based on U.S.

Forest Service Region 6 supplement to

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If possible, avoid footnotes by enclosing explanatory material in parentheses in the text. Unpublished references should be listed as footnotes (see PERMISSIONS).

TABLES

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Table 3--Distribution of egg masses on sample branches

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Figure 4.--Distribution of veneer volume of logs.

Computer plotting on the Wang 700A-720C[1/] series programable calculator can increase the speed and accuracy of graph preparation. DeMars and Thompson (1977) explain this process in USDA Forest Service Research Note PNW-289, "Computer Plotting of Graphs for Reports." Proper preparation of the plotting points by the author is essential.

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Stein, William I., and Peyton W. Owston. 1977. Containerized seedlings in western reforestation. J. For. 75(9):575-578, illus.

Books

Author(s)
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Bollen, W. B., and K. C. Lu. 1968. Nitrogen transformations in soils beneath red alder and conifers. In Biology of alder. J. M. Trappe, J. F. Franklin, R. F. Tarrant, and G. M. Hansen, eds. p. 141-148. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Thesis, if Available

Hazard, John William. 1969. Optimal replacement strategy for successive forest surveys with multiple objectives. Ph. D. thesis. Iowa State Univ., Ames.

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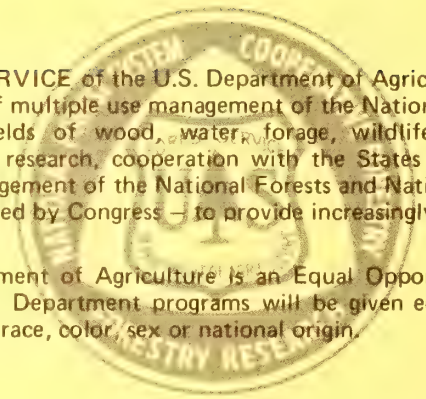

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USDA FOREST SERVICE RESEARCH NOTE

PNW-311 January 1978

RATES OF SPREAD OF WILDFIRE IN ALASKAN FUELS

by

Richard J. Barney, Nonan V. Noste, and Ralph A. Wilson [1/]

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ABSTRACT

Fire spread relationships are needed as a basis for categorizing and quantifying "real world" rates of fire spread in Alaska. The rate of fire spread predicted by the fuel models used to develop the National Fire-Danger Rating System were related to actual rates of spread observed on wildfires. General fuel models and local weather information provide a fairly accurate prediction of rate of spread. Data discussed can provide an interim guide for decisions on fire management and land management planning.

KEYWORDS: Fire behavior (forest), fire danger rating, fuel (forest fire), wildfire, tundra, Alaska, models.

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INTRODUCTION

There is a need for quantitative measures of rates of spread of wildfire for various Alaskan fuels. Information on fire spread in the interior of Alaska is almost nonexistent. The basic objective of this study is to provide field data from observations of fire in Alaskan fuels. There is a need for fire models for fire management and land management planning that can be used as a basis for comparison and further refinement of fuel models and fire behavior models.

Determination of rates of fire spread is very important in control operations, not only for long-range planning but for dispatching the initial attack. Fire spread rates are also important to the land management planner in assessing possible outcomes of alternate management strategies. A concerted effort has been made to develop rate-of-spread prediction models for fires (Rothermel 1972). As pointed out by Albini (1976b), fire behavior models have a wide array of potential uses, ranging from land use planning to prescribed fire design to decisionmaking. Today we use the inputs of fire behavior models in the National Fire-Danger Rating System (NFDRS) (USDA Forest Service 1964) and in fire control planning.

Actual rates of spread were obtained to help verify mathematical predictions. The rate-of-spread observations reported are an attempt to provide a reference for management applications and future research efforts. Results reported offer a basis for projecting rates of spread in Alaska and also a basis for selecting fuel models for use in several management operations.

METHODS

Forest Service field crews measured rates of spread of wildfires in various fuel types and under various weather conditions throughout interior Alaska during the fire seasons of 1969, 1970, and 1971.

The Alaskan Bureau of Land Management fire control organization is occasionally overloaded by large numbers of concurrent lightning fires, and control action is taken according to a priority plan. As a consequence we were able to use free-spreading (control action deferred) fires for making our observations. Many levels of fire intensities were encountered, including extreme conditions during difficult fires and fire seasons. Observations were made when opportunities arose. The number of observations reflect this and are concentrated in more severe weather and fuel conditions.

We used a hand-held wind meter and a sling psychrometer to record the weather. Wind was measured at midflame height where values might be expected to be somewhat lower than standard 20-foot, open anemometer heights.

Only the general overall advancement of the fire front was considered important, so rate of spread was observed as a wave front phenomenon. Microscale observations, such as ignition of individual fuel particles, were not made. Spot fires were watched and considered in the computation of rate-of-spread measurement only if they contributed to the

general spread of fire. Fires were observed on the heading (burning forward or upslope), backing (burning into the wind), and flanking (burning to the side) sections. Rate-of-spread observations were made for a minimum of 10 minutes, or a minimum spread of 100 feet. Rate of spread was then reported as feet per minute averages.

Procedures were necessarily flexible to cope with the wide range of conditions and situations encountered in wildfires. Measurement of distance was more refined for slower spread conditions. A tape was used to either estimate paces or measure distances on slow-moving fires. A pacing check for each observer was made prior to determining high rates of spread where pacing was necessary. Equipment used included a stopwatch, flagging, belt weather kit, forms, and instructions.

Each observation was begun by hanging flagging ahead of the fire front and measuring the distance to another flag located along a line normal to the flame front. The progress of the fire between flags was timed with a stopwatch. Current weather was observed simultaneously at a short distance (50 feet) from the fire where the radiation and wind effect of the fire were judged to be negligible.

ANALYSIS

The data were stratified to provide meaningful input to fire models. The primary stratifications for our analysis were cover type (fuel) and direction of spread of fire (heading, backing, or flanking). Mature and young cover types were pooled, then analyzed. The broader cover types of conifer, hardwood, mixed conifer-hardwood, shrubs and brush, leaves, grass, and tundra were used.

Because of the relatively small amount of field collected data, considerable variation was encountered. Results of the analysis shown here are, however, an attempt to provide information on spread of fires in Alaskan fuel types. They also show the fit of the model data with observed field data.

Rate-of-spread averages for fuel types and direction of fire spread were developed. Data from all weather conditions were pooled for the various factors and then averaged (table 1). Maximum and minimum spread rates are also shown to indicate the ranges encountered.

To relate field observations of fire spread to existing fire spread models, we used the various fuel models available (Deeming and Brown 1975, Albini 1976a) to compare our data with predicted rates of spread. Ambient weather conditions for a majority of our data were within a temperature range of 50°F to 69°F and relative humidities of 35 to 44 percent. Such conditions would result in a 1-hour timelag fuel moisture of 6 percent and a 10-hour timelag fuel moisture of 8 percent (Deeming et al. 1974).[2/] Using some basic data from another research study,[3/] we estimated the 100-hour timelag fuel moisture to

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[2/] See Deeming et al. (1977) for definitions of timelag fuels and timelag fuel moisture.

[3/] Barney, Richard J. Fuel moisture relationships in four Alaskan cover types. Unpublished report, on file at Institute of Northern Forestry, Fairbanks, Alaska.

Table 1--*Maximum, minimum, and average rate-of-spread values by fuel type and direction of fire*

Fuel type	Spread direction	Number of observations (N)	Maximum rate of spread	Minimum rate of spread	Average rate of spread
			- - - Feet per minute[1/] - - -		
Conifer	Heading	13	66.0	1.0	15.35
	Backing	30	2.1	.1	.98
	Flanking	21	9.0	.3	1.94
Hardwood	Backing	2	3.0	.5	1.75
Mixed hardwood and conifer	Heading	3	6.9	1.8	4.3
	Backing	8	8.9	.2	3.8
	Flanking	1	--	--	1.0
Shrubs and brush	Heading	9	4.1	.7	2.60
	Backing	22	2.7	.9	1.94
	Flanking	3	2.3	1.5	1.97
Tundra, weeds, and grass	Heading	1	--	--	1.1
	Backing	15	2.0	.1	.85
	Flanking	2	1.7	1.0	1.35

[1/] To obtain chains per minute, multiply feet per minute by 0.0152; to obtain chains per hour, multiply feet per minute by 0.909.

be 25 percent and green fuel moisture to be 60 percent. These estimates were substituted for fuel moistures which could not be measured in the field.

Fuel models were selected to represent cover types where spread rates were observed. These fuel models were NFDRS models E, F, and H (Deeming and Brown 1975). In addition, Northern Forest Fire Laboratory (NFFL) modifications of these fuel models were used (Albini 1976a). General descriptions of NFDRS fuel models are shown in table 2.

We used computer programs (Albini 1976a) to calculate rates of fire spread for selected fuel types and plotted the resultant curves. Our rate-of-spread observations in the field were then plotted on these graphs by cover type. We selected models which appeared to best fit our data.

Table 2--*Brief descriptions of National Fire-Danger Rating fuel models*[1/]

NFDR fuel model	Characteristics of fuels	Examples
E	The fuel is primarily made up of hardwood leaf litter. It is made up of only 1-hour and 10-hour timelag fuels that are not compacted.	Closed canopy stands consisting of long-needled pines or hardwood stands prior to litter compaction including all oak-hickory associations
F	A dense cover of young shrubs containing small amounts of dead material characterizes this fuel. This fuel has little grass or litter which will carry the fire, and the foliage will not burn well.	Shrub association such as laurel, alder, manzanita, mountain mahogany, and young chamise
H	Compact litter with branchwood of moderate loading is found in this type. Fuels of the 1-hour, 10-hour, and 100-hour timelag categories are present.	Northern hardwoods; hardwoods after leaf fall becomes compacted litter; and short-needled conifers

[1/] Adapted from Deeming and Brown (1975). More complete descriptions and a key for field use are contained in Deeming et al. (1974).

We were unable to identify and stratify the spread rates by fuel loadings in a manner compatible with the Rothermel spread model. Fuel loading was a refinement brought about after the early examination of these data. Nevertheless, information obtained in this initial work can be useful to those in fire control and fire planning activities within interior Alaska, as well as to other interested scientists.

When these study data are reviewed and the information applied, the generally accepted fire rate of spread and windspeed relationships in fine fuels must be kept firmly in mind (fig. 1). Forward rate of

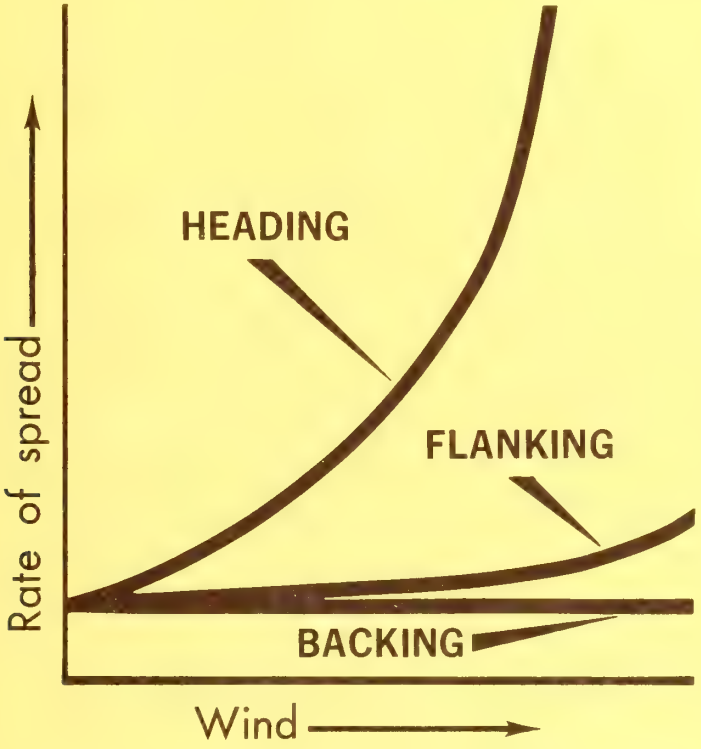

Figure 1.--Characteristic rate-of-spread curves of fires as wind increases.

spread is generally considered to increase as windspeed increases (Rothermel and Anderson 1966). The rate of spread of a backing fire is essentially constant throughout change of windspeed (Beaufait 1965). Flanking fires, however, generally increase their rate of spread with an increase in wind, but at a lower rate than a head fire.

Rates of Spread for Heading Fires

Rates of fire spread for the conifer fuel type were observed. Figure 2A shows these results. For the spread rates observed for heading fires in conifers there is a definite curvilinear relationship with windspeed. Although there is a considerable amount of scatter about the curve, the lower ranges of the data do show an expected pattern of increased spread rates with increasing windspeed. When

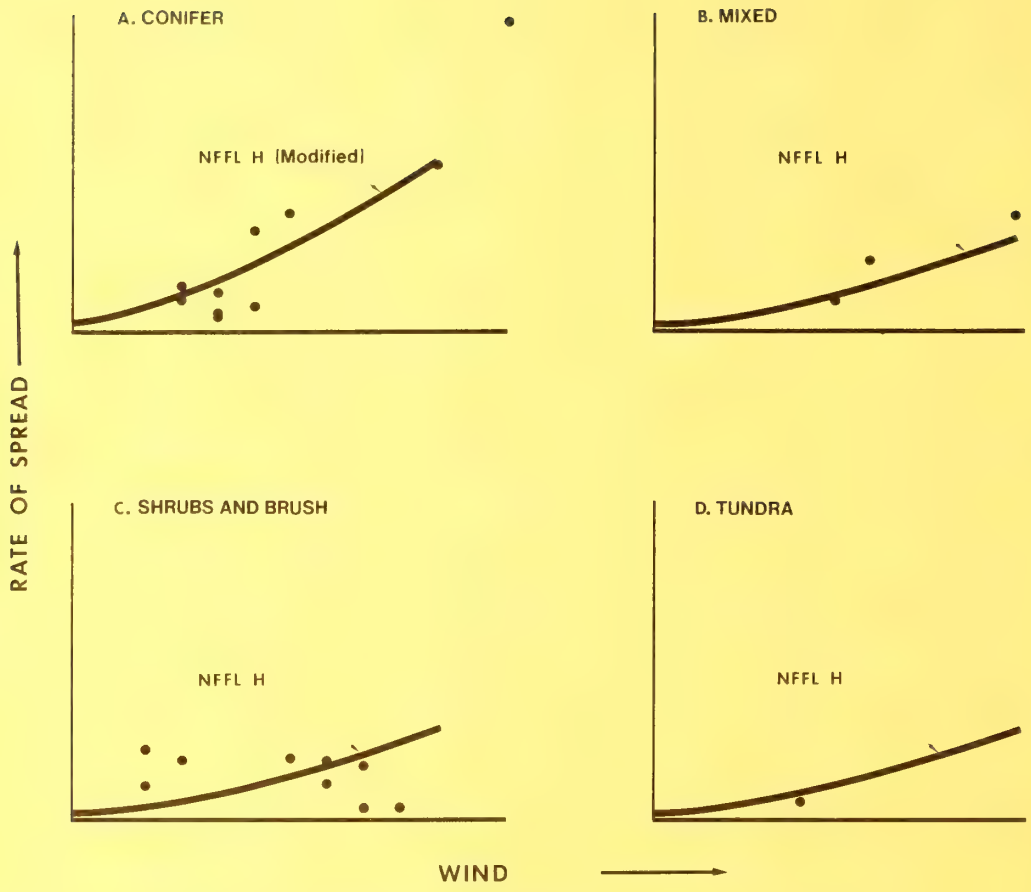

Figure 2.-- Rate-of-spread curves of heading fires in various fuels as wind increases.

figure 2A was plotted three data points were omitted; these points were fire spread observations with flame lengths of 80 feet. Fires of such magnitude are not adequately represented by the Rothermel spread model. The modified NFFL fuel model H seems to fit the rest of the observed data fairly well.

The mixed, shrubs and brush, and tundra data for heading fires are compared with data plotted by the NFFL H fuel model. Although the data for the mixed fuel (fig. 2B) are limited (three points), they do fit fairly well with the plotted curve. Data for shrubs and brush fit least well with the plotted curve. In some respects the data hint at an inverse relationship--that fire spread decreases slightly with an increase of wind (fig. 2C). The one point for a tundra fire fits fairly well with the NFFL model H curve (fig. 2D).

After the observed and the predicted spread data derived from the ambient conditions and fuel models were analyzed, the NFFL model H appeared to best fit our data. By slightly modifying the NFFL model H by increasing the depth of the fuel bed, we obtained an even better fit

with the conifer data of the NFFL model H (modified). For each data plot displayed and discussed, we have plotted the predicted rate-of-spread curve for comparison. The specific fuel model inputs are shown in table 3; data presently incorporated in the NFDRS fuel model H are

Table 3--*Principal descriptors*[1/] *of fuel models*

Fuel model	Fuel loadings by classes				Surface-volume ratio by classes				Bed depth[2/]	Moisture extinction dead fuel
	W_1	W_{10}	W_{100}	W_{Live}	σ_1	σ_{10}	σ_{100}	σ_{Live}		
	- - - Tons per acre - -				- - - - - - Feet^{-1} - - - - - -				Feet	Percent
National Fire Danger Rating System model H	1.0	1.0	1.0	--	2000	109	30	--	0.4	0.25
Northern Forest Fire Laboratory model H	1.5	1.0	2.5	--	2000	109	30	--	.2	.25
Northern Forest Fire Laboratory model H (modified)	1.5	1.0	2.5	--	2000	109	30	--	.3	.25

[1/] Descriptor subscripts indicate 1-hour, 10-hour, and 100-hour timelags, and living woody fuel classes.

[2/] Bed depth represents average depth of the fuel bed, all fuels touching the surface.

also shown. Basically, the NFFL H and NFFL H (modified) have a greater loading than the NFDRS model H in the 1-hour and 100-hour timelag fuels and also have a slightly deeper fuel bed. Rate-of-spread outputs for NFFL fuel models H and H (modified) are shown in table 4. Byram's (1959) fireline intensity is also shown.

One must keep in mind that the NFFL H and H (modified) curves were developed for selected weather and fuel moisture data. Our spread observations were not stratified by moisture in these plots, and different comparisons probably would have resulted had this been done. For so few points, however, stratification is not reasonable. Had more specific fuel loading and moisture content data been available for our field observations, we could have done more in the way of validating the spread model.

Rates of Spread of Backing Fires

For backing fires the spread rates for conifer fuel (fig. 3A), for weeds, grass, and tundra (fig. 3B), and for shrubs and brush (fig. 3C) are relatively constant as windspeed increases. In figure 3, A and B, rate of spread appears to increase as wind increases up to about 5 miles per hour. As the windspeed continues to increase, the rate of spread appears to drop off slightly. The data for backing fires follow the generalized spread relationships (fig. 1) of an essentially constant rate as wind increases.

Data plotted for the mixed (hardwood and conifer) type (fig. 3D) and the hardwood type (fig. 3E) illustrate more scatter. The rate of spread varies because of the heterogeneous nature of ground fuels in the mixed cover type, as well as the extreme variation in fuel moisture both vertically and horizontally (see footnote 2, p. 3). The limited

Table 4--*Rate-of-spread outputs for Northern Forest Fire Laboratory fuel models H and H (modified)*

Windspeed at midflame height		Rate of spread	Byram's intensity[1/]
Miles per hour	Feet per minute	Feet per minute	Btu per minute per fireline foot
		MODEL H	
0	0	0.25	44.2
1.0	88.00	.42	73.6
2.0	176.00	.72	126.5
3.0	264.00	1.11	194.5
4.0	352.00	1.57	274.6
5.0	440.00	2.08	365.1
6.0	528.00	2.65	464.9
7.0	616.00	3.27	573.0
8.0	704.00	3.93	689.0
9.0	792.00	4.63	812.2
10.0	880.00	5.38	942.2
		MODEL H (MODIFIED)	
0	0	0.41	113.4
1.0	88.00	.73	200.5
2.0	176.00	1.30	357.1
3.0	264.00	2.03	558.3
4.0	352.00	2.90	795.3
5.0	440.00	3.87	1,063.2
6.0	528.00	4.95	1,358.4
7.0	616.00	6.12	1,678.5
8.0	704.00	7.37	2,021.6
9.0	792.00	8.70	2,386.2
10.0	880.00	10.10	2,771.0

[1/] Byram (1959).

data do not support the backing curve of figure 1; they appear to show an increase in spread of fire as wind increases, whereas the model indicates a steady rate or even a decreased rate of spread with an increase in windspeed. Stratification of data by moisture levels and fuel loadings might well change this situation, however.

Rates of Spread of Flanking Fires

Much of the data show similar rates of spread for flanking and backing fires (fig. 4). These rates of spread are slightly slower for higher windspeeds, however. The rate of fire spread in the conifer cover type varies considerably, probably because of the variation in the amount and moisture of the fuel.

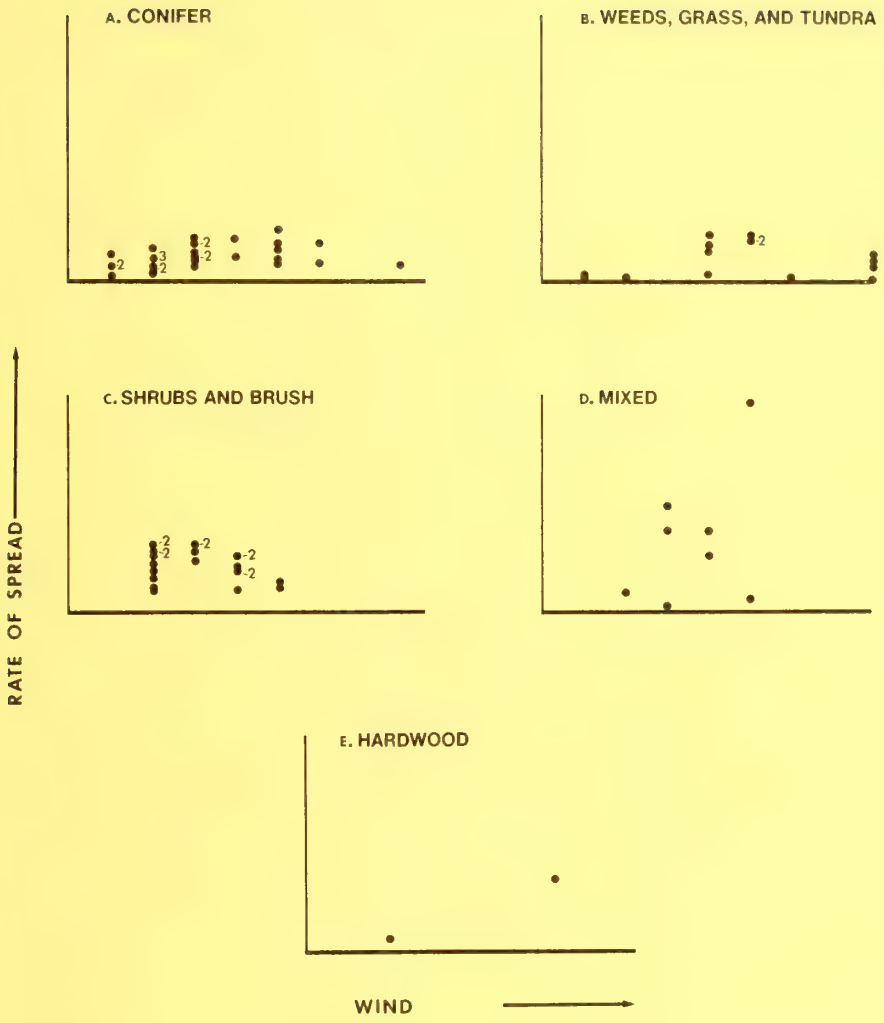

Figure 3.--Spread rates of backing fires in various fuels as wind increases.

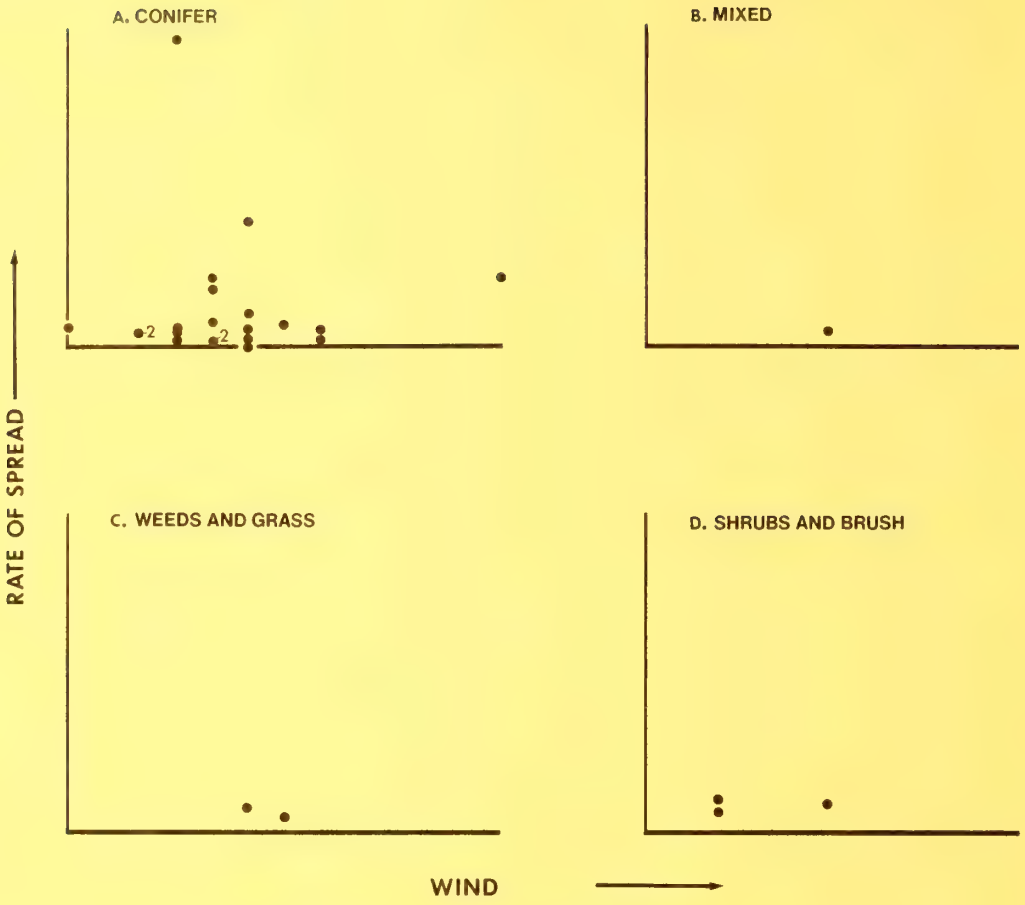

Figure 4.--Spread rates of flanking fires in various fuels as wind increases.

DISCUSSION AND CONCLUSIONS

Although the data vary considerably, they do provide some quantitative measures of fire spread for the various types of fuel in Alaska. The fuel models provide a basis for planning for both fire control and land management. We hope these data will help managers make a more accurate evaluation and projection of rates of spread than have been available for fuels in interior Alaska. The fuel models, along with local weather information, should give a fairly accurate prediction of rates of fire spread.

More data are needed, for both numbers of observations and types of data. More fuel moisture and fuel loading data along with fire

spread rates would allow verification of spread and refinement of fire behavior models. Some relationships are weak, but they are a start at categorizing and quantifying "real world" rates of fire spread in Alaska. Continued work in describing the various fuels in Alaska, along with more sophisticated measurements of spread, will improve our understanding. These data can be used as an interim guide in making decisions on a quantitative basis, but the variations and limited amount of data must be kept in mind.

ACKNOWLEDGMENTS

The Office of Civil Defense provided partial funding for this study.

The U.S. Department of the Interior, Bureau of Land Management, Alaska Division of Fire Control, provided cooperation and logistical support.

CONVERSION FACTORS

If units are:	You can find:	If you multiply by:
feet	centimeters	30.48
miles	kilometers	1.61
degrees Fahrenheit	degrees Celsius	5/9 (after subtracting 32)

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GPO 985-118

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-312 February 1978

SEEDING HABITS OF UPPER-SLOPE TREE SPECIES

IV. SEED FLIGHT OF NOBLE FIR AND PACIFIC SILVER FIR

by

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Jack Booth, *Forestry Technician*, and Clark E. Smith, *Forestry Technician*[1/]

ABSTRACT

Noble and Pacific silver fir seed fall declined rapidly as distance from uncut timber at the edge of clearcuts increased. Observations were made at four locations in the Washington and Oregon Cascade Range. There were no differences in dispersal of sound and unsound noble fir seed but unsound Pacific silver fir seed dispersed farther than sound seed. Pacific silver fir had a higher percentage of sound seed than noble fir had for the same seed year. Differences in effectiveness of east and west cutting boundaries in seed dispersal were not consistent.

KEYWORDS: Seed dispersion, elevation, noble fir, *Abies procera*, Pacific silver fir, *Abies amabilis*, clearcutting systems.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of personnel from McKenzie Bridge Ranger District, Willamette National Forest, and Mount Adams Ranger District, Gifford Pinchot National Forest, in collecting contents of seed traps. U.S. Forest Service, Region 6, provided the seed traps.

[1/] Clark E. Smith is no longer employed by the Pacific Northwest Forest and Range Experiment Station.

INTRODUCTION

A research program on natural regeneration of upper-slope forests in the Pacific Northwest was begun in 1961 with a long-term study of cone production of major timber species (Franklin 1968, Franklin et al. 1974). In 1967 the research was extended to include production of viable seed and seed dissemination throughout clearcut areas.

This note reports data on seed flight of noble fir (*Abies procera* Rehd.) and Pacific silver fir (*Abies amabilis* (Dougl.) Forbes) for 1968-69 and 1971-72 seed years in the Washington and Oregon Cascade Range. Earlier reports have described the flight of seeds from mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) (Franklin and Smith 1974a), and mixed white fir (*Abies concolor* (Gord. & Glend.) Lindl.) and Shasta red fir (*A. magnifica* var. *shastensis* Lemm.)(Franklin and Smith 1974b). This note describes relationships between seed fall and distance from the uncut timber at the edge of a clearcut. Results provide general information concerning seed supply for natural regeneration of these species. The data should be helpful in selecting size of clearcut where natural regeneration will be used to establish part or all of the new crop.

STUDY AREA

The study areas were located in the Willamette National Forest in Oregon and Gifford Pinchot National Forest in Washington (table 1). Three areas were selected primarily for their noble fir and the fourth area was selected for its Pacific silver fir[2/]. Each area

[2/] Initially two study areas were selected to represent Pacific silver fir for the 1968-69 and 1971-72 seed years. Vandalism reduced data so that one area had to be removed from the study. The other area, Mosquito Lake, though vandalized, had a usable 1968-69 seed year collection.

Table 1-- *Location and physical characteristics of study areas*

Area	National Forest	Ranger District	Topography	Elevation	
				Feet	Meters
Wildcat	Willamette	McKenzie Bridge	Moderate to steep mountain slopes	4,800	1 465
Bingham Ridge	Wilamette	Detroit	Very gently sloping	5,000	1 525
Sleeping Beauty-Ninefoot Creek	Gifford Pinchot	Mount Adams	Moderate slopes on a ridge	4,000	1 220
Mosquito Lake	Gifford Pinchot	Mount Adams	Gently undulating	3,900	1 190

had transects from both an east and a west uncut edge of a clearcut (fig. 1). In two areas (Wildcat and Sleeping Beauty-Ninefoot Creek) the east and west transects were on different clearcuts. Bingham Ridge had a narrow clearcut and shared the 375-foot (114-m) transect.

Physical features of each area were recorded, and the uncut timber stand was inventoried to characterize the seed source. The basal area of species of trees 5 inches (13 cm) d.b.h. and larger was recorded for 1-acre (0.4-ha) plots at both the east and west edge of uncut timber (table 2).

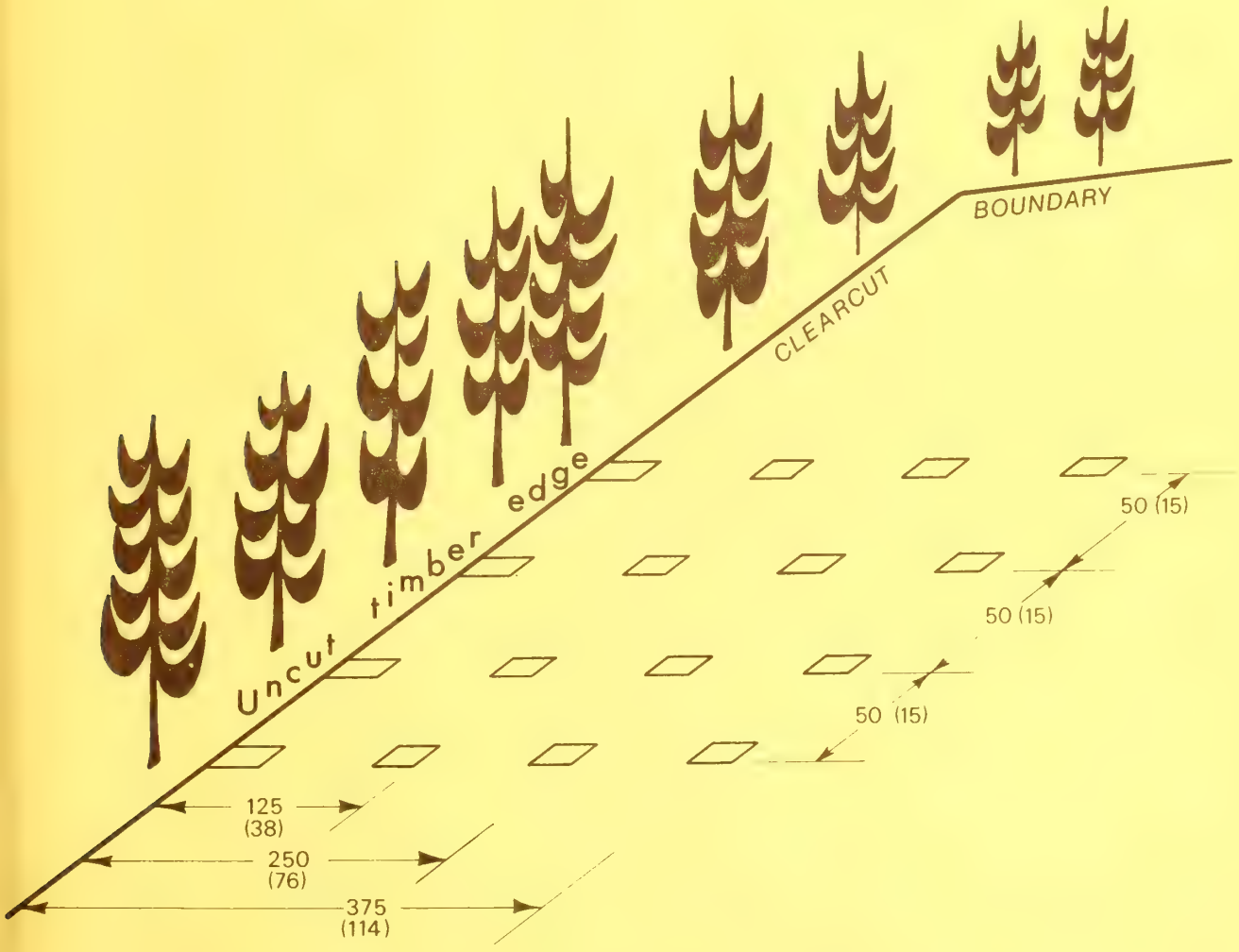


Figure 1.--Arrangement of seed trap transects from an east or west seed source in feet (meters).

Table 2--*Basal area of uncut trees*[1/] *on edges of study areas, in square feet per acre (square meters per hectare)*

Area	Edge	Trees per acre	Trees per hectare	Noble fir	Pacific silver fir	Douglas-fir	Grand fir	Mountain hemlock	Western hemlock	Western white pine	Total
Wildcat	East	194	479	229 (53)				1 (0.2)			230 (53)
	West	100	247	379 (87)		85 (20)	4 (1)	1 (.2)		3 (0.7)	472 (109)
Bingham Ridge	East	182	449	410 (94)		122 (28)	1 (.2)	11 (3)		7 (1.6)	551 (127)
	West	150	370	171 (39)		265 (61)	8 (2)		1 (.2)		445 (102)
Sleeping Beauty-Ninefoot Creek	East	147	363	195 (45)	4 (1)	229 (53)			1 (.2)		429 (99)
	West	172	425	213 (49)		250 (57)			17 (4)		480 (110)
Mosquito Lake	East	163	403		257 (59)			44 (10)	6 (1.4)	8 (2)	315 (72)
	West	93	230		285 (65)			29 (7)		8 (2)	322 (74)

[1/] Basal area and trees per acre are for trees over 5 inches (13 cm) d.b.h. on a 1-acre (0.4-ha) plot.

METHODS

Numbers of seed falling at various distances from the stand edge were measured by catching seed in 1- by 2-foot (0.3- by 0.6-m) seed traps. The seed traps were placed along transects at right angles from the timber edge toward the center of each clearcut (fig. 2). Sixteen seed traps were used in each transect; four traps were placed at 0, 125, 250, and 375 feet (0, 38, 76, and 114 m) from the edge of the timber (fig. 2). Seed traps followed Herman's (1963) design with an additional crossmember in the top half to support the heavy snow loads characteristic of Pacific Northwest high-elevation areas. Seed were collected about October 1 and November 1 and again the following spring as soon as snowmelt occurred. Seed soundness was determined by a cutting test.

Regression analyses were calculated for total seed fall and sound seed fall for each transect by distance from stand edge. Other regressions were calculated separately and in combination for the 1968-69 and 1971-72 seed years. The regression model was

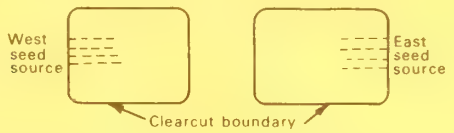
$$\text{Log } (y+1) = a + b(1/(x+1)) \quad ;$$

where, y = number of seed per trap and x = distance from stand edge.

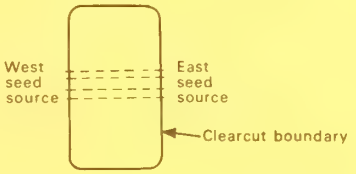
RESULTS

Seed fall rapidly declines as distance from the stand edge increases. This pattern is similar for both seed years (fig. 3). The regression model was fitted to the data; results of the statistical tests are found in table 3. Noble fir seed fall declines more rapidly than that of Pacific silver fir (table 4). At 125 feet (38 m) Pacific silver fir seed fall is nearly the same as at the stand edge, but noble fir seed fall

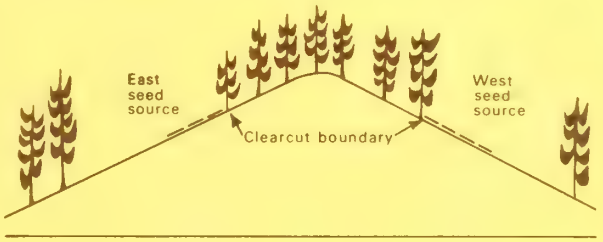
WILDCAT—East and west transects are in separate clearcuts



BINGHAM RIDGE—Since clearcut is narrow, east and west transects share the 375-foot (114-m) set of seed traps.



SLEEPING BEAUTY-NINEFOOT CREEK—East and west transects are on separate clearcuts several miles apart on opposite sides of a common ridge.



MOSQUITO LAKE—East and west transects in the same clearcut

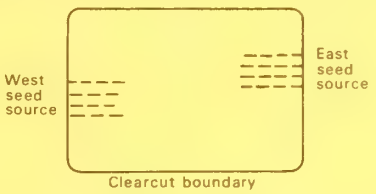
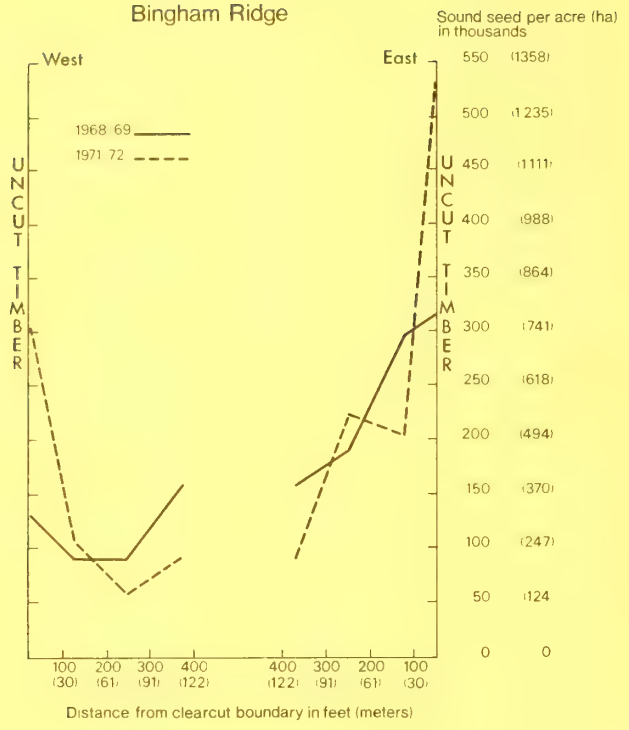


Figure 2.--Description and layout of clearcuts and seed trap transects.



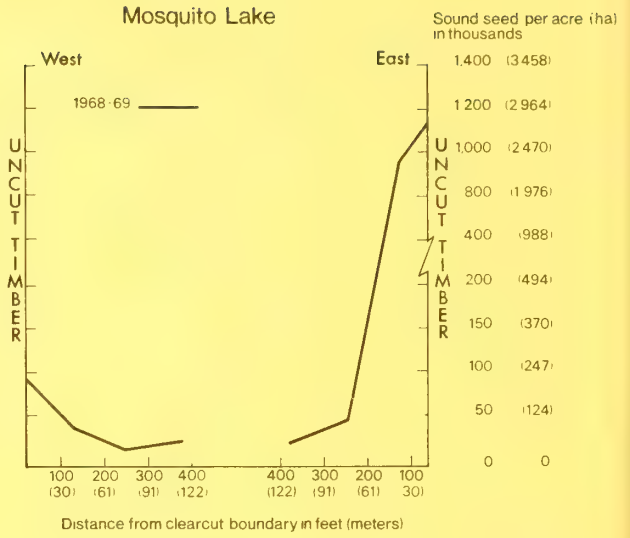
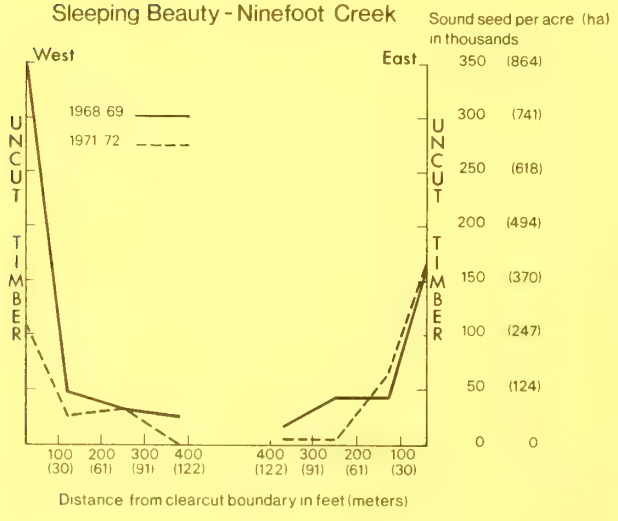


Figure 3.--Average seed fall from the 1968-69 and 1971-72 noble fir and Pacific silver fir seed crops, by distance from east and west clearcut boundaries.



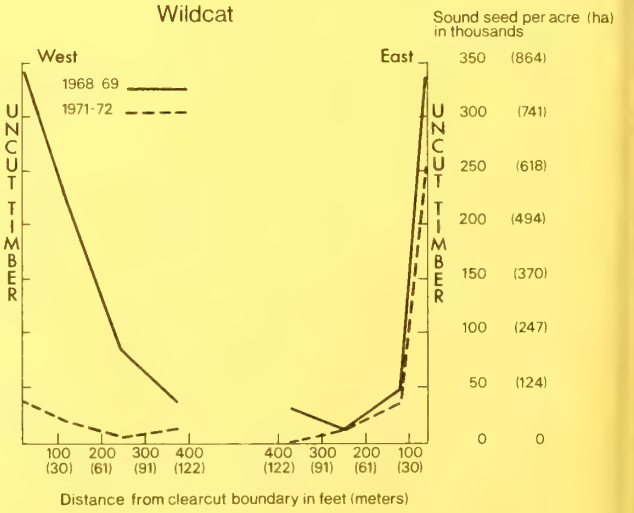


Table 3--*Regression models for total seed fall, seed years 1968-69 and 1971-72 combined, by area and by stand edge*

Species and location	Stand edge	Regression model[1/]	
Noble fir:			
Wildcat	East	Log (y + 1) = 1.9 + 0.74 (1/(x + 1))	
	West	Log (y + 1) = 2.2 + 0.13 (1/(x + 1))	N.S.
Bingham Ridge	East	Log (y + 1) = 2.7 - 0.12 (1/(x + 1))	N.S.
	West	Log (y + 1) = 2.5 + 0.38 (1/(x + 1))	
Sleeping Beauty	East	Log (y + 1) = 2.0 + 0.78 (1/(x + 1))	
	West	Log (y + 1) = 2.0 + 0.61 (1/(x + 1))	
Pacific silver fir:			
Mosquito Lake	East	Log (y + 1) = 2.5 - 0.32 (1/(x + 1))	N.S.
	West	Log (y + 1) = 1.3 + 0.69 (1/(x + 1))	

[1/] Significance level of t-test statistic for regression model was calculated at the 5-percent level; N.S. - nonsignificant.

has declined by two-thirds. About 10 percent of the seed of both species were collected at 375 feet (114 m). Sound and unsound seed of noble fir behaved similarly (table 4); that is, the percentage of sound and unsound seed at various distances from the stand edge are about the same. Unsound Pacific silver fir seed did fly farther on the average than sound seed, and the percentage of unsound seed at 125 feet (38 m) increased as distance from the stand edge increased (table 4).

There are some major differences between east and west stand edges in both the absolute level and the distribution of seed fall as distance from the stand edge increases (fig. 3) (table 5). Stand condition

Table 4--*Noble and Pacific silver fir seed trapped at various distances from the stand edge*

Species and seed type	Distance in feet (meters)			
	0	125 (38)	250 (76)	375 (114)
	- - - - - - - - - - Percent - - - - - - - - - -			
Noble fir:				
Sound	59	19	13	9
Unsound	56	21	13	10
Average	57	20	13	10
Pacific silver fir:				
Sound	41	34	16	9
Unsound	32	37	18	13
Average	37	35	17	11

Table 5 --*Seeds collected on the transects at the east and west sides of clearcut units, seed years 1968-69 and 1971-72 combined*

Species and area	Side of clearcut			
	West		East	
	Number	Percent	Number	Percent
Noble fir:				
Bingham Ridge	609	35	1,155	65
Wildcat	622	57	466	43
Sleeping beauty-Ninefoot Creek	444	50	444	50
Pacific silver fir:				
Mosquito Lake[1/]	80	7	1,023	93

[1/] Only 1968-69 seed year.

appears to be the primary factor influencing the total amount of seed. Of the three noble fir areas, Bingham Ridge had the most striking contrast in seed fall on east and west sides of the clearcut. Bingham Ridge also had the largest difference in basal area between east and west: 410 ft^2 per acre (94 m^2/ha) and 171 ft^2 per acre (39 m^2/ha)(table 2). At Wildcat, though there were more trees per acre on the east edge, the major factor affecting noble fir seed fall was apparently the high basal area per acre of noble fir on the west edge; basal area of noble fir on the west edge is over 1-1/2 times larger than on the east edge.

There are no consistent differences in the rate at which seed fall declines with distance between east and west clearcut boundaries (fig. 3). For example, at Wildcat noble fir seed dispersal was more effective from the west boundary in 1968-69 and from the east boundary in 1971-72. At Bingham Ridge dispersal of noble fir seed was more effective from the east boundary both years.

The percentage of sound noble fir seed from the 1968-69 and 1971-72 seed years ranged from 17.4 to 48.0. Total seed fall was higher in 1968-69 than in 1971-72, but the percentage of sound seed was lower, 21.0 versus 34.7 percent:

Area	Percent of sound seed	
	1968-69	1971-72
Wildcat	24.8	24.3
Bingham Ridge	20.5	48.0
Sleeping Beauty-Ninefoot Creek	17.4	31.8
	21.0	34.7

At Mosquito Lake 51 percent of Pacific silver fir seed was sound in the 1968-69 seed year.

DISCUSSION

The rapid decline in seed fall as distance from the stand edge increases is similar to results found with other upper-slope tree species--mountain hemlock (Franklin and Smith 1974a) and white and shasta red fir (Franklin and Smith 1974b). Response has been similar for light-seeded species--lodgepole pine (*Pinus contorta* Dougl.) in south-central Oregon (Dahms 1963), spruce-fir (*Picea* A. Dietr. *Abies* Mill.) in eastern Maine (Randall 1974), and Engelmann spruce (*Picea engelmannii* Parry) in the Rocky Mountains (Roe 1967).

Despite the rapid decline in seed fall as distance from the stand edge increases, large numbers of seeds are dispersed at least 375 feet (114 m) in bumper years. Average seed dispersed per acre for this distance in the 1968-69 year were 33,000 noble fir and 125,000 Pacific silver fir. Given reasonably favorable conditions for seed survival and germination and seedling establishment, these figures suggest more than adequate supplies of seed for natural restocking of small--10- to 20-acre (4- to 8-ha)--clearcuts.

The comparison of east and west cutting boundaries was an attempt to determine whether a primary direction of dispersal could be identified. A predominance of either southwest or east winds as the dispersal agent would presumably be responsible. Unfortunately, the data are insufficient to allow any conclusions.

The Bingham Ridge clearcut was a special case with the east and west transects sharing the set of seed traps at 375 feet. In this area seed from the dense noble fir stand on the east boundary of the clearcut appeared to be dispersed beyond the center of the unit in sufficient numbers to cause a skewed pattern in seed fall (fig. 3). Gratkowski (1958) observed a similar asymetrical pattern in Shasta red fir seed fall on a small clearcut.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-313

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FIELD LIFE OF ORTHENE®, SEVIN®-4-OIL AND DYLOX®1.5 BIOASSAY WITH DOUGLAS-FIR TUSSOCK MOTH LARVAE[1]

by

George P. Markin, J. Wayne Brewer, and Harold O. Batzer[2]

Insecticides, Sevin®-4-oil, Dylox®-1.5 and Orthene®75S were evaluated to determine their field life against the Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough). Tests were conducted by treating 15-acre field plots by helicopter and collecting foliage samples for bioassay in the laboratory with 3d-instar larvae.

Sevin-4-oil showed little loss of residual activity for 14 days after application. Dylox-1.5 residues killed less than half the test insects after 3 days although some residual activity could be found after 14 days. The short field life of Dylox may have been partly because of rainfall, which either hydrolyzed or washed it off the foliage. Most residual activity of Orthene was gone after 7 days under the field conditions studied.

KEYWORDS: Pesticide residues, bioassay, insecticides (-forest pests, Orthene, Sevin-4-oil, Dylox, Douglas-fir tussock moth, *Orgyia pseudotsugata*.

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[1]Funding for this study was supplied by the USDA Expanded DFTM Research and Development Program, K. H. Wright, Director, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, Oregon.

[2]George P. Markin is with the USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, 2810 Chiles Road, Davis, California; J. Wayne Brewer is with the Department of Zoology and Entomology, Colorado State University, Ft. Collins, Colorado; and Harold O. Batzer is with the USDA Forest Service, North Central Experiment Station, 1992 Folwell Ave., St. Paul, Minnesota.

INTRODUCTION

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough) is an important defoliator of Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco, and grand fir, *Abies grandis* (Dougl.) Lindl., in Western North America. During periodic outbreaks, extensive top killing, loss of growth, or outright killing of trees may result (Wickman 1963, Wickman et al. 1973).

In 1975, the U.S. Forest Service established a series of field tests to evaluate three chemical insecticides,[3] Sevin®-4-oil, Dylox®-1.5 and Orthene® 75S applied aerially with two spray systems producing different droplet sizes.[4] Susceptibility of different larval instars to one of the pesticides, Orthene (acephate), was also studied.[5]

The residual activity of the three materials under actual field conditions of a western coniferous forest is unknown, yet such information is necessary for choosing optimum timing of treatment by an insecticide. Should an insecticide be applied after hatch has occurred, sacrificing the new foliage consumed before treatment? Or should it be applied before hatch, letting the residual activity of the material kill the insects as they emerge, maximizing foliage protection?

As part of the 1975 Douglas-fir tussock moth program, a series of tests was set up to answer these questions.

MATERIALS AND METHODS

The study plots were on the Wenatchee National Forest on the east side of the Cascade Range about 20 miles (33 km) northwest of Ellensburg, Washington. Laboratory facilities were at the Department of Biology, Central Washington State College at Ellensburg.

Twelve plots, each 16 acres (6.5 hectare) and separated from each other by a minimum of 0.5 mile (0.8 km), were selected for the test. The three treatments and untreated control were replicated three times in a random block design with all replicates of a particular treatment at about the same elevation. In the center 2 acres (0.8 hectare) of each plot, 15 open-grown trees, both Douglas-fir and grand fir 30 to 60 ft high (9 to 18 m), were selected as sample trees. Application was made when 90 percent of the bud caps had fallen from the new growth of Douglas-fir.

All applications were made with a Hiller 12 E helicopter using a 30-ft (9.14-m) boom equipped with Spraying Systems (Wheaton, Illinois) T8002 flat fan nozzle tips. Spraying started on the downwind side of the plot and progressed upwind with swaths spaced 50 ft (15 m) apart and the helicopter flying 35 to 50 ft (11-15 m) above the treetops.

Sevin®-4-oil was diluted 1:1 with diesel oil and applied at the rate of 2 lb AI/acre in 1 gal of formulation. Dylox®-1.5 containing 1.5 lbs AI/gal of carrier oil, was applied undiluted at the rate of 1 gal/acre. Orthene® 75S was applied at 1 lb AI/acre in 2 gal water. Each gallon (3.789 l) of spray solution contained 3.8 grams of Rhodamine B dye for spray deposit

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[3] Mention of a proprietory product does not constitute an endorsement by the USDA. This paper reports the results of research work only. Mention of a pesticide does not constitute a recommendation for use by the USDA, nor does it imply registration unless specifically stated. All uses of pesticide must be registered by the appropriate State and Federal agencies before they can be recommended.

[4] Markin, G. P., R. Orchard, H. O. Batzer, and J. W. Brewer. 1975. Effectiveness of three insecticides applied at droplet sizes for control of the Douglas-fir tussock moth and western spruce budworm. Manuscript in preparation.

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assessment. For Sevin and Dylox, the dye was first mixed in oleic acid (94.6 ml/gal) to make it more soluble in oil.

Spray deposit was sampled with two aluminum plates and one white Kromekote card placed in an open area adjacent to each sample tree. The amount of deposit was determined by fluorescent methods (Yates and Akesson 1963) and converted to gallons per acre. Droplet density and volume-median diameter[6] of deposit were determined with a Quantimet 720 (Imanco Image Analyzing Computer and Co., Monsey, N.Y.), which electronically measured and counted droplets larger than 20 micrometers.

Samples were collected 24 hr before treatment and at 30 min (Sevin and Dylox) or 24 hr (Orthene) and 3, 7, and 14 days after treatment. Samples were collected with an extendable pole pruner to remove three branch tips 14 to 16 inches (35.5 to 40 cm) long from the midcrown of each tree. Immediately after collection, the needles were removed from the basal 4 inches (10 cm) of the stems. The 3 branches from each tree were then placed in a perforated plastic bag and the sack sealed around the stems. The foliage was transported to the laboratory where within 5 hours after collecting, the base of the branches were placed in water (fig. 1). In each sack, ten 3d-instar, laboratory-reared Douglas-fir tussock moths were introduced through a slit in the sack, which was later closed. The insects were allowed to feed for 7 days, after which the sack was opened and the number of dead and live larvae counted to determine the percent mortality. Similar samples were collected from trees in untreated plots to serve as controls. Results were converted to

Figure 1.--Foliage placed in plastic bags and used to bioassay Douglas-fir tussock moth larvae.

percent mortality for each insecticide and analyzed for analysis of variance using a simple contrast between the various sampling intervals. All differences were judged for significance at the 0.05 level.

Applications were made on June 16 (Orthene) and June 18 (Sevin and Dylox). Two short, intense rain showers occurred late in the afternoon of June 18, 0.3 in (0.8 cm), and June 19, 0.2 in (0.5 cm). Thus, rain fell on the Orthene plots 2 days after treatment and on the Sevin and Dylox plots 7-10 hours after application and again after 31 to 34 hours. No detectable rainfall occurred during the remaining 2 weeks of the study.

RESULTS AND DISCUSSION

Results of spray deposit analysis are shown in table 1. Variation in the amount of material recovered is considered normal, because several outside factors (such as wind, temperature, and canopy density) can significantly affect the amount of material reaching the ground surface. At best, spray recovery

[6]Volume median diameter is the droplet diameter satisfying the requirement that half of the volume of liquid is in droplets smaller and half is in droplets larger than the vmd.

Table 1--*Spray deposit from aerial application to field plots, 1975*

Treatment	Replicate	Application		Atomization	Recovered deposit	
		Active ingredient	Spray volume			
		Lb/acre	Gal/acre	µm	Droplet/cm^2	Gal/acre
Sevin-4-oil	A	2	1	316	11.9	0.051
	B	2	1	336	17.2	.118
	C	2	1	253	16.9	.113
Average				302	15.3	.094
Dylox-1.5	A	1.5	1	331	1.7	.044
	B	1.5	1	331	7.0	.383
	C	1.5	1	352	6.1	.230
Average				338	4.9	.219
Orthene 75S	A	1	2	253	29.1	.764
	B	1	2	243	12.9	.579
	C	1	2	256	11.7	.590
Average				251	17.9	.644

at ground level can only be used as an approximation of the amount and droplet size of the deposit reaching the forest canopy.

The plastic sack allowed the foliage to remain fresh and attractive to the insects for the 7 days. The development of the insects on the foliage from pretreatment collection and check plots appeared to be similar to insects being reared on artificial diets.

The mortality (table 2) is based on the percentage of dead insects found in the same sack after 7 days

Table 2--*Douglas-fir tussock moth mortality in laboratory bioassay of treated foliage using 3d-instar larvae, mortality determined after 10 days of exposure*

Treatment	Replicate	Percent mortality from foliage collected at:											
		Pretreat		30 min		1 day		3 days		7 days		14 days	
		Mean[1]	SE[2]	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Sevin-4-oil	A	2.0	1.3	92.0	5.0			78.5	5.8	89.2	5.0	82.0	7.7
	B	2.0	1.3	70.7	5.9			72.0	7.6	88.0	6.7	84.7	5.3
	C	7.0	3.1	97.9	2.0			87.2	3.7	86.0	5.6	94.7	3.3
Average		3.7a	1.7	86.9b	8.3			79.2b	4.4	87.7b	.9	87.1b	3.9
Dylox-1.5	A	1.0	1.0	51.7	7.6			4.7	1.6	16.7	3.9	5.3	5.3
	B	2.0	1.3	65.3	7.5			12.0	2.4	12.0	3.0	4.7	1.9
	C	2.0	1.3	82.7	7.2			8.7	3.6	6.0	3.7	11.3	6.6
Average		1.7a	.3	66.6b	9.0			8.5a	2.1	11.6a	3.1	7.1a	2.1
Orthene 75S	A	1.0	.7			88.0	6.6	31.3	9.4	14.1	3.8	8.0	3.4
	B	0.0	0.0			60.0	12.2	47.3	11.7	7.3	2.1	19.3	4.7
	C	2.3	1.0			94.7	2.7	78.0	7.4	12.0	2.2	4.0	1.6
Average		1.1a	0.7			80.9b	10.6	52.3b	13.7	11.1a	2.0	10.4a	4.6
Control plots	A	0.0	0.0			4.0	1.3			6.0	2.2	4.0	1.6
	B	0.0	0.0			4.0	1.3			6.0	1.6	4.0	2.1
	C	2.0	1.3			1.0	1.0			5.0	2.2	4.0	1.3
Average		.7	.7			3.0	1.0			5.7	.33	4.0	0.0

[1]For a given insecticide averages followed by the same letter are not significantly different; $P \leq 0.05$.

[2]The standard errors shown for each replicate are within plot sampling error based on 15 trees. The standard errors for the averages are based on the average of the 3 replicates.

of feeding, averaged for the 15 samples per plot. The field life of Sevin for the 2 weeks of the study was excellent. The residual activity of Dylox was very low; 3 days after treatment all activity had been lost. Some of the loss of activity is attributed to rain showers that occurred on the day that the Dylox 1.5 was sprayed. At a temperature of 20°C, Dylox is 9-percent soluble in water and is also readily hydrolyzed.[7]

Information provided by the manufacturer of Orthene suggested that Orthene has some systemic activity and that, within a few hours after treatment, some material should be absorbed into the treated foliage providing some residual activity. The bioassay, however, indicated that under our test conditions little residual activity remained after 7 days.

CONCLUSIONS

The relatively long residual activity of Sevin suggests that it might be applied early in the larval stage of the tussock moth to ensure maximum foliage protection. Treatment programs could begin at or before larval hatch because sufficient quantities would remain active until hatch was completed. Because of the short field life of Dylox and its rapid deactivation by water, we suggest that application of this material be delayed until hatch of the tussock moth is complete and the larvae are on the new foliage and fully exposed. Also, application should be made when no heavy dew is on the foliage and no rain predicted for 24 hr.

Orthene had a very short field life. For this reason its application should be delayed until the new larvae are exposed and feeding on the new foliage.

[7]Technial Information Sheet, "Dylox Insecticides" by Chemagro Agricultural Division, Mobay Chemical Corporation, Kansas City, Missouri. March 1973.

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The authors wish to express their appreciation to the Department of Biology at Central Washington State College, Ellensburg, Washington, and in particular to Dr. Sheldon Johnson and Dr. Stamford D. Smith, for their help in organizing this test, providing laboratory space and equipment, and particularly for help in hiring and directing the summer field crew.

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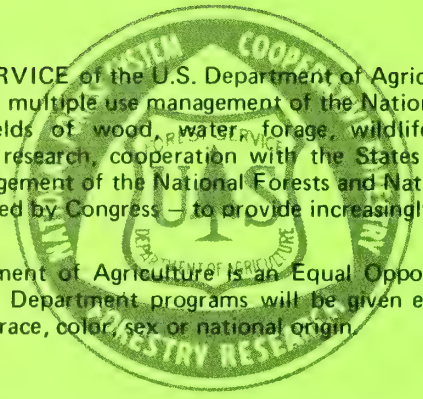

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-314 February 1978

POPULATION AND COMMUNITY RESPONSES OF SMALL MAMMALS TO 2,4,5-T

by

Gordon L. Kirkland, Jr. [1/]

FEB 19 1981

ABSTRACT

The population and community responses of small mammals to application of the herbicide 2,4,5-T were studied on the Fernow Experimental Forest, Parsons, West Virginia. Data from live-trap and snap-trap sampling of small mammals before and after herbicide treatment revealed either neutral or positive responses. There was a significant correlation between the ranked order of abundance of species in pretreatment and posttreatment samples; this indicated that no major shift in community composition had occurred. Total numbers of small mammals tended to increase after aerial application of the herbicide. Shrews (Soricidae) and mice (Cricetinae) increased significantly; voles (Microtinae) declined slightly. The decrease in the abundance of microtine rodents resulted from a differential decline in the abundance of diurnal species.

KEYWORDS: Herbicide side effects, population dynamics, animal populations, Mammalia, herbicides (-forest weed control, 2,4,5-T.

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INTRODUCTION

On August 5, 1975, watershed 6 (WS-6) on the Fernow Experimental Forest near Parsons, West Virginia, was treated with an aerial application of the herbicide 2,4,5-T[2/] to release planted Norway spruce *(Picea abies)*[3/] from competing vegetation. This provided an opportunity to examine the responses of small mammals to the herbicide. Small mammal populations on WS-6, which had previously been sampled in October 1974, were sampled in July and October 1975 and July and August 1976. Based on the results of these 2,640 trap nights (TN) of sampling effort, this note presents an assessment of the population and community responses of small mammals to the 2,4,5-T treatment of WS-6.

SITE DESCRIPTION

Watershed 6 is located 3.6 km south and 0.7 km west of Parsons, Tucker County. The study site has a mean elevation of 820 m with a general southeast aspect. In 1963, the mixed deciduous forests, dominated by chestnut oak *(Quercus prinus)* and northern red oak *(Q. rubra)*, were clearcut and herbicides applied for six succeeding growing seasons. Since 1969, succession on the watershed has been allowed to proceed; in July 1975 the watershed was characterized by a mosaic of saplings and shrubs, interspersed with patches of grasses and ferns. Dominant tree species were black locust *(Robinia pseudoacacia)*, sumac *(Rhus* sp.*)*, cherry *(Prunus* sp.*)*, devil's walking stick *(Aralia spinosa)*, tulip poplar *(Liriodendron tulipifera)*, sugar maple *(Acer saccharum)*, and yellow birch *(Betula lenta)*. Blackberry and raspberry *(Rubus* spp.*)* were abundant.

METHODS AND MATERIALS

The 2,4,5-T was applied as a propylene glycol butyl ester in a water and oil emulsion by helicopter with a microfoil boom. Each 0.405 ha of the 21.45-ha watershed received 4.41 kg of 2,4,5-T (acid equivalent) in 1.89 liters of no. 2 diesel oil mixed with water to make 18.93 liters. The herbicide killed or controlled all vegetation except grasses and ferns. An estimated 85 to 95 percent of the foliage of woody species, including *Rubus*, was killed. Following herbicide treatment, patches of grasses and ferns appeared as green islands in a brown landscape.

Small mammals were sampled on one live-trap and two snap-trap grids. Each grid consisted of 80 stations with 15.25 m between lines and stations, for an effective sampling area of 1.86 ha. At each station, three traps were set within 1 m of the station marker. Museum Special[4/] breakback snap traps were used on the snap-trap grids, and 7.6- by 8.9- by 22.9-cm Sherman live traps on the live-trap grid. All traps were baited with rolled oats. Specimens captured alive were marked by clipping their toes; they were released at the site of capture. The goal of releasing seedling spruce from competition by application of 2,4,5-T on all of WS-6 precluded the establishment of an untreated grid as a control.

[2/] (2,4,5-trichlorophenoxy) acetic acid.

[3/] Authorities for scientific names are: Fernald (1950) for trees, Hall and Kelson (1959) for mammals and for family names.

[4/] Mention of products by name is for the information and convenience of the reader and does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Grids were run for 3 nights in July but only 2 nights in October because of the limitations of weekend sampling. The grid types and sampling dates were: grid A, snap trap, October 18-20, 1974; grid B, snap trap, October 24-26, 1975; and grid C, live trap, July 28-31, and October 24-26, 1975, and July 30 and August 1, 1976.

RESULTS AND DISCUSSION

A total of 286 small mammals representing nine species were trapped (table 1). Statistical analyses of capture data from preherbicide and postherbicide sampling determined that quantitative and qualitative changes in the resident small mammal community generally were not pronounced.

Table 1--*Mammals captured and selected population parameters for three sampling grids before and after application of 2,4,5-T on watershed 6, Fernow Experimental Forest*

	Before application of herbicide			After application of herbicide			
Sampling grid	A	C	Total	B	C	C	Total
Date sampled	10/74	7/75		10/75	10/75	7-8/76	
Capture method[1/]	K	L		K	L	L	
Number of trap nights	480	720	1,200	480	480	480	1,440
Short-tailed shrew *(Blarina brevicauda)*	12	8	20	21	20	3	44
Masked shrew *(Sorex cinereus)*	4		4	3	1		4
Smokey shrew *(Sorex fumeus)*	6	1	7	16	8	6	30
Deer mouse *(Peromyscus maniculatus)*	11	12	23	16	35	6	57
White-footed mouse *(Peromyscus leucopus)*		7	7	5	1		6
Meadow vole *(Microtus pennsylvanicus)*	8		8	2			2
Southern bog lemming *(Synaptomys cooperi)*	3		3				
Red-backed vole *(Clethrionomys gapperi)*	10	18	28	11	24	7	42
Woodland jumping mouse *(Napaeozapus insignis)*		1	1				
Total	54	47	101	74	89	22	185
Catch per 100 trap nights	11.3	6.5	8.4	15.4	18.4	4.6	12.8
Soricids (percent)	40.7	19.1	30.7	54.1	34.5	40.9	42.2
Cricetines (percent)	20.4	40.4	29.7	28.4	42.9	27.3	34.1
Microtines (percent)	38.8	38.3	38.6	17.6	28.6	31.8	23.8

[1/] K means a snaptrap was used; L means a live trap was used.

The ranked order of abundance of species did not change significantly after herbicide treatment. Spearman Rank Correlation analysis (Siegel 1956) of capture totals from pretreatment and posttreatment samples revealed a significant correlation between the relative abundance of species before and after the herbicide was applied ($r_S = 0.84$, $p < 0.01$). This was in spite of the failure after the herbicide application to capture two species present in pretreatment samples; however, the southern bog lemming *(Synaptomys cooperi)* and the woodland jumping mouse *(Napaeozapus insignis)*, were the two least abundant species before application of the herbicide. *N. insignis* likely was in hibernation during the October sampling periods (Whitaker and Wrigley 1972).

The abundance of small mammals as measured by catch per unit sampling effort (number of captures per 100 TN) tended to be greater in postherbicide treatment samples. The increase in abundance of small mammals on the snap-trap grids between October 1974 (grid A, 11.3 per 100 TN) and October 1975 (grid B, 15.4 per 100 TN) was not statistically significant. There was a slight decrease in the relative abundance on the live-trap grid (C) between July 1975 (6.5 per 100 TN) and July and August 1976 (4.6 per 100 TN). The relative abundance of small mammals on the live-trap grid (C), however, increased significantly between July (6.5 per 100 TN) and October (18.4 per 100 TN) 1975 ($\chi^2 = 36.67$, $p < 0.001$).

Equally as important as the significant increase in abundance of small mammals on the live-trap grid between July and October 1975 was the recapture in October of 18 of 44 individuals marked in July (table 2). This 41-percent recapture rate verified a substantial survival of individuals on the sampling grid immediately prior to herbicide treatment and permitted rejection of the hypothesis that the October 1975 small mammal population on WS-6 was composed of individuals that had immigrated to the area after extirpation of the original population by the herbicide treatment. Instead, the October 1975 population consisted of individuals present before the treatment, plus others added through birth or immigration.

Table 2--*Mammals recaptured on live-trap grid, watershed 6, Fernow Experimental Forest*

Species	Number marked July 1975	Number recaptured October 1975	Percent
Blarina brevicauda	7	2	28.6
Sorex fumeus	1	0	0
Peromyscus maniculatus	12	9	75.0
Peromyscus leucopus	7	1	14.3
Clethrionomys gapperi	16	6	37.5
Napaeozapus insignis	1	0	0
Total	44	18	--

Comparison of pretreatment and posttreatment samples of small mammals reveals changes in the relative abundance and community composition of shrews (Soricidae), mice (Cricetinae), and voles (Microtinae). After treatment, the proportions of soricids and cricetines in the samples increased, whereas that of microtines decreased. Analyses of these changes with a z-test for differences in proportions (Zar 1974) indicate that the changes in soricids from 30.7 percent in pretreatment samples to 42.2 percent in posttreatment samples and in cricetines from 29.7 to 34.1 percent were not statistically significant at the 0.05 level. The decrease in the proportion of microtines in the samples, however, from 38.6 percent in pretreatment samples to 23.8 percent after herbicide treatment was significant ($z = 2.64$, $p < 0.01$).

These changes in community composition reflect shifts in the relative abundance (catch per 100 TN) of these groups before and after treatment. Soricids increased significantly from 2.58 per 100 TN to 5.42 per 100 TN ($\chi^2 = 12.72$, $p < 0.001$), as did cricetines from 2.50 per 100 TN to 4.38 per 100 TN ($\chi^2 = 6.53$, $p < 0.02$). In contrast, numbers of microtines declined slightly from 3.25 per 100 TN to 3.06 per 100 TN. Thus, the shift in the proportion of microtines (grazers) after treatment resulted from their failure to increase in abundance while the other two taxa increased significantly.

Of the three groups of mammals, the microtines should be the most likely to be adversely affected by the herbicide. Being primarily grazers, they might be affected by the decrease in vegetative food resources and/or by ingestion of the herbicide. The food habits of the cricetines and soricids should render them less susceptible to either of these effects, since the former are predominantly seed eaters and the latter insectivores.

The failure of the Microtinae to increase in abundance after the herbicide treatment may also be related to the loss of vegetative cover. In this study, two types of microtines were captured, primarily diurnal grassland species--the meadow vole *(Microtus pennsylvanicus)*, the bog lemming and a more nocturnal forest-dwelling species, the red-backed vole *(Clethrionomys gapperi)*. The trapping data reveal differential population responses in these two types of microtines. *Microtus pennsylvanicus* and *S. cooperi* declined significantly from 0.92 per 100 TN before the herbicide was applied to 0.14 per 100 TN after treatment ($\chi^2 = 8.03$, $p < 0.01$). During the same period, *C. gapperi* increased from 2.33 per 100 TN to 2.97 per 100 TN. Thus, the overall decline in microtines after treatment is attributable to the differential decrease in the abundance of the diurnal grassland species, possibly as a result of being exposed to increased predator pressure through the loss of vegetative cover. Birney et al. (1976) note that a minimal level of vegetative cover is necessary to permit *Microtus* spp. to increase in numbers during multiannual population fluctuations, and that insufficient cover exposes diurnal *Microtus* to increased predation from vision-oriented diurnal predators.

Other species of small mammals were not similarly affected for several reasons. Members of the genus *Peromyscus* are almost exclusively nocturnal, and *Clethrionomys*

gapperi are most active from sunset to sunrise (Banfield 1974). Although soricids are generally active throughout each 24-hour day, they may be exposed to less diurnal predator pressure than microtines because of their small size. In addition, *Blarina brevicauda* is most active under the leaf and grass litter and in the tunnels it constructs below the surface of the soil.

CONCLUSIONS AND SUMMARY

In spite of the logical assumption that the application of 2,4,5-T and/or the accompanying habitat alterations might have produced a general negative response in the original small mammal community, data from this study reveal that only the microtines responded negatively. The food habits and behavior of some species of the Microtinae may have made them more sensitive than either the cricetines or soricids to the impact of the herbicide. In spite of increases and decreases in the abundance of various species, community composition, as measured by the ranked order of abundance of species in pretreatment and posttreatment samples, did not change significantly. Total small mammal abundance either remained statistically unchanged or increased after herbicide treatment. The increase in small mammal abundance between July and October 1975 may have represented a normal seasonal fluctuation rather than a positive response to the herbicide.

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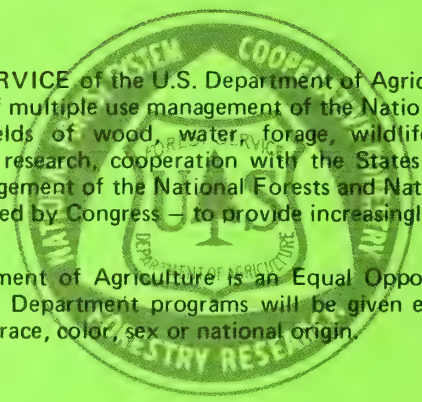

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-315 March 1978

PHYSICAL PROPERTIES OF WOODY FUELS IN THE BLUE MOUNTAINS OF OREGON AND WASHINGTON

by

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and

Stewart G. Pickford, *Assistant Professor* [1]

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Abstract

Physical properties were determined for some fuels in the surface litter of stands in the Blue Mountains of Oregon and Washington. Average and quadratic mean diameters for both 0- to 1/4-inch and 1/4- to 1-inch fuels were determined in stands of Douglas-fir and grand fir, western larch, lodgepole pine, ponderosa pine, subalpine fir, and Engelmann spruce. Specific gravities were also determined for both size classes of Douglas-fir, grand fir, western larch, and lodgepole pine fuels. The heat content was also determined for 0- to 1/4-inch and 1/4- to 1-inch fuels of Douglas-fir, grand fir, western larch, and lodgepole pine and for composite samples of litter and duff. Diameters of particles of some species were significantly different from values reported for similar fuels in Montana. Use of local diameter measurements to calculate fuel loading from planar intersect sampling reduced bias in predicted loadings 4 to 57 percent. Differences in predicted loading caused by use of local determinations of specific gravity ranged from 2 to 44 percent. The heat contents of Blue Mountain fuels were similar to values reported in other regions of the country.

KEYWORDS: Wood properties (physical), fuels (forest fire), fuel survey, calorific value (wood), specific gravity (wood), Oregon (Blue Mountains), Washington (Blue Mountains).

---

[1] Kevin Ryan is with the Pacific Northwest Forest and Range Experiment Station. Stewart G. Pickford is with the University of Washington, Seattle.

INTRODUCTION

Prior to the development of the Rothermel (1972) fire spread model, assessments of wildfire hazards were based largely on qualitative evaluation of fuel complexes. The model provides a means for assessing fire spread and intensity given quantitative data on fuels, topography, and probable weather. As a result, more objective fire behavior predictions and, consequently, better assessments of fire hazard can be made.

Input parameters in the Rothermel (1972) model include the ratio of surface area to volume, particle density, low heat content, and fuel loading and depth. The ratio of surface area to volume is calculated from the average diameter (d_a) for each size class of fuel. Particle density is derived from the specific gravity (s) of the fuel. The low heat of combustion is derived from calorimeter tests in the laboratory. Fuel loading and depth are generally determined from field inventory of the fuel complex being modeled.

Brown (1974) standardized field inventory procedures for quantifying downed woody fuels. These inventories provide estimates of the loading (weight per unit area) and depth of particles making up the fuel complex. By Brown's technique, fuel loading for pieces less than 3 inches in diameter can be determined from the equation:

$$W = \frac{11.64 \times n \times d_q^2 \times s \times a \times c}{N\ell}$$

where

W = fuel loading (tons per acre)
n = number of intercepts
d_q = quadratic mean diameter (inches)
s = specific gravity
a = average secant of nonhorizontal angle
c = slope correction factor
N = number of transects
ℓ = length of transect (feet)

In the equation, only d_q, s, and a depend on species. Therefore, the accuracy of inventory estimates will depend, in part, on the values used for these properties. Brown and Roussopoulos (1974) determined that use of the quadratic mean diameter instead of the average diameter reduced bias as much as 16 percent. They also determined that inclusion of a in the equation reduced bias in predicted loading as much as 39 percent.

The d_q and s values obtained in one region may be questionable for inventories of fuel-producing tree species in a different region because of genetic or site variation. Brown (1974) suggests values for d_q (obtained from Brown and Roussopoulos (1974)) and s which can be used for calculating fuel loading. Although these values were determined in the northern Rocky Mountains, they have been used in eastern Oregon and Washington because local data have been lacking.

An extensive inventory of fuel and appraisal of fire hazard in the Blue Mountains of Oregon and Washington were undertaken as part of the Douglas-fir Tussock Moth Program.[2/] As part of this study, samples were taken to determine representative values for d_q and s and to see if significant differences exist between Blue Mountain values and those suggested by Brown (1974). In addition to d_q and s, the high heat of combustion was determined for some common Blue Mountain fuels. The results of the diameter, specific gravity, and heat of combustion determinations are reported. Also, fuel loadings predicted by Brown's (1974) data are compared with loadings from data collected in the Blue Mountains.

[2]The research reported here was financed in part by the USDA Expanded Douglas-fir Tussock Moth Research and Development Program.

METHODS

Field

The study area is situated in the Blue Mountains of Oregon and Washington. The area on which sampling was done lies between Walla Walla and Pomeroy, Washington, on the north and Tollgate and Troy, Oregon, on the south. Forest cover consists primarily of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Dougl.) Lindl.), and ponderosa pine (*Pinus ponderosa* Laws.) at elevations of less than about 4,500 feet. Above this elevation, subalpine fir (*A. lasiocarpa* (Hook.) Nutt.), Engelmann spruce (*Picea engelmannii* Parry), western larch (*Larix occidentalis* Nutt.) and lodgepole pine (*P. contorta* Dougl.) predominate.

For each species, two or three stands were selected for the inventory of fuel properties. Stands were located several miles apart so that the range of conditions could be sampled. Douglas-fir and grand fir occurred in nearly equal proportions in the stands selected for measurement, and particle diameters were not identified by species. Stands of the other species were essentially pure, and particle diameters were identified by species. Particles were sampled along an engineer's tape laid between two trees in each stand. The diameter of each twig (0- to 1/4-inch) or branch (1/4- to 1-inch) intersected by the edge of the tape was measured at the point of intersection to the nearest one-hundred-twenty-eighth of an inch with a caliper. When all particles along the tape were measured, the tape was moved to a new pair of trees and the procedure repeated until an adequate sample had been obtained. The average secant of nonhorizontal angle was not measured because of the preponderance of horizontally distributed particles.

Separate samples of twig and branch material of Douglas-fir, grand fir, western larch, and lodgepole pine were collected for determinations of specific gravity and heat of combustion. Composite samples of duff (L, F, and H layers) were collected from seven stands and placed in soil moisture cans. The seven samples were combined for determination of an average heat of combustion for duff.

Laboratory

The 0- to 1/4-inch and 1/4- to 1-inch material collected in each of four species constituted eight separate samples. From each of the eight samples, four pieces were randomly selected for a representative subsample. An estimate of the sample's average specific gravity was obtained by separating the sample into four groups corresponding to the subsample by which they appeared to be represented. Average specific gravity for material in each sample was then determined by weighting each subsample's specific gravity by the proportion of weight in the group to total sample weight. The air-dry volume of each subsample was determined by immersing the subsample in a graduated cylinder filled with mercury. The volume determination by mercury displacement is a nonstandard technique developed for conifer needles[3] and modified for twigs and branches.[4] The volume of displaced mercury was read with a cathetometer with an accuracy of about $\pm$ 1 percent. Subsamples were ovendried and weighed to $\pm 1.8 \times 10^{-5}$ ounces.

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[3] Bunnell, David L. 1968. Method and technique of deriving specific gravity of conifer needles. Unpublished report on file at USDA For. Serv. Intermt. For. and Range Exp. Stn., North. For. Fire Lab., Missoula, Mont., 7 p.

[4] Tuttle, Kenneth L. 1976. Tussock moth wildfire fuels specific gravity and higher heating value determinations. Unpublished report on file at USDA For. Serv. For. Residues Program, Pac. Northwest For. and Range Exp. Stn., Portland, Oreg., 15 p.

Material from each of the eight twig samples was ground to obtain a particle size suitable for determinations of moisture and heat of combustion. Duff samples were ground and separated according to ASTM (American Society for Testing and Materials 1947) method D-21. Half of each sample by weight was combined, mixed, and tested for moisture content and heat of combustion. Moisture contents and higher heating values were determined in duplicate for the ground samples according to ASTM method D-271, except that moisture contents were determined by drying samples at 212°-219°F for 16 hours.

RESULTS AND DISCUSSION

Particle Diameter

Although the individual diameter measurements within a class are not normally distributed, the Central Limit Theorem is assumed to apply to d_a samples of the size collected. Based on this assumption, a test of equality of sample variances of the two populations was conducted. Where significant differences in variance existed, an approximate t-test (Snedecor and Cochran 1967) for unpaired data was used to compare d_a from the two samples. A pooled t-test was used where differences were not significant.

The t-test revealed that the average diameters of some Blue Mountain species and size classes are significantly different from average diameters of similar species and size classes reported by Brown and Roussopoulos (1974) (table 1). Although differences were found, no consistent patterns emerged. For the Blue Mountain data, average diameters for 0- to 1/4-inch western larch, subalpine fir, and

Table 1--*Comparison of Blue Mountain fuel particle average diameters (d_a) and variances with values obtained by Brown and Roussopoulos (1974)*

Species	Diameter class	Blue Mountains			Brown and Roussopoulos[1/]			F[2/]	t[3/]
		d_a	n	Standard deviation	d_a	n	Standard deviation		
		Inches		Inches	Inches		Inches		
Douglas-fir/ grand fir	0-1/4	0.107	234	0.161	0.098	1.052	0.051	9.96*	0.846
	1/4-1	.452	101	.662	.512	1,030	.213	8.14*	-.906
Western larch	0-1/4	.140	262	.044	.114	716	.051	1.37*	7.831**
	1/4-1	.399	176	.150	.453	967	.185	1.52*	-4.227**
Lodgepole pine	0-1/4	.123	200	.052	.134	225	.043	1.50*	-2.359*
	1/4-1	.435	100	.179	.547	228	.213	1.42	4.604**
Ponderosa pine	0-1/4	.179	28	.265	.177	206	.051	27.00*	.040
	1/4-1	.473	100	.704	.453	967	.185	14.49*	.283
Subalpine fir	0-1/4	.119	306	.051	.098	1,052	.051	1.00	6.175**
	1/4-1	.425	109	.166	.512	1,030	.213	1.64*	-5.049**
Engelmann spruce	0-1/4	.127	238	.055	.098	1,052	.051	1.15	7.760**
	1/4-1	.491	147	.198	.512	1,030	.213	1.16	-1.103

[1/] Values from table 1, Brown and Roussopoulos (1974).

[2/] F-test of the equality of the two population variances.

[3/] t-test of the equality of the two population average diameters.

* Significant at the 0.05 level.
** Significant at the 0.01 level.

Material from each of the eight twig samples was ground to obtain a particle size suitable for determinations of moisture and heat of combustion. Duff samples were ground and separated according to ASTM (American Society for Testing and Materials 1947) method D-21. Half of each sample by weight was combined, mixed, and tested for moisture content and heat of combustion. Moisture contents and higher heating values were determined in duplicate for the ground samples according to ASTM method D-271, except that moisture contents were determined by drying samples at 212°-219°F for 16 hours.

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Table 1.—Comparison of Blue Mountain fuel particle average diameters (d_a) and variances with values obtained by Brown and Roussopoulos (1974)

Species	Diameter class	Blue Mountains d_a	Blue Mountains n	Blue Mountains Standard deviation	Brown and Roussopoulos[1] d_a	Brown and Roussopoulos[1] n	Brown and Roussopoulos[1] Standard deviation	F[2]	t[3]
		Inches		Inches	Inches		Inches		
Douglas-fir/ grand fir	0-1/4	0.107	234	0.054	0.098	1,052	0.051	1.11	2.415*
	1/4-1	.452	101	.163	.512	1,030	.213	1.71**	-3.424**
Western larch	0-1/4	.140	262	.044	.114	716	.051	1.36**	7.831**
	1/4-1	.399	175	.150	.453	967	.185	1.53**	-4.217**
Lodgepole pine	0-1/4	.123	200	.052	.134	225	.043	1.43**	-2.359*
	1/4-1	.435	100	.179	.547	228	.213	1.41	-4.914**
Ponderosa pine	0-1/4	.179	28	.061	.177	206	.051	1.42	.190
	1/4-1	.478	100	.185	.453	967	.185	1.00	1.286
Subalpine fir	0-1/4	.119	306	.051	.098	1,052	.051	1.02	6.340**
	1/4-1	.425	109	.166	.512	1,030	.213	1.64**	-5.049**
Engelmann spruce	0-1/4	.127	238	.055	.098	1,052	.051	1.15	7.806**
	1/4-1	.491	147	.198	.512	1,030	.213	1.16	-1.128

[1] Values from table 1, Brown and Roussopoulos (1974).

[2] F-test of the equality of the two population variances.

[3] t-test of the equality of the two population average diameters.

* Significant at the 0.05 level.
** Significant at the 0.01 level.

E R R A T A: Please replace pages 4 and 5 of USDA Forest Service Research Note PNW-315 HYSICAL PROPERTIES OF WOODY FUELS IN THE BLUE MOUNTAINS OF OREGON AND WASHINGTON, by evin C. Ryan & Stewart G. Pickford, with these revised, corrected pages.

Englemann spruce intercepts were greater than Brown and Roussopoulos (1974) had found; but for lodgepole pine they were less. For intercepts greater than one-fourth inch, Brown and Roussopoulos' d_q's generally were greater. There were only three cases in which the variance and/or mean were not significantly different at the .05 level.

The effect of differences in the two diameter distributions on predicted loadings was determined by calculating the quadratic mean diameters for the Blue Mountain data and comparing them to the quadratic mean diameters reported by Brown and Roussopoulos (1974) and Brown (1974). Use of the Blue Mountain dq^2 values instead of those suggested by Brown (1974) would result in calculated fuel loading differences ranging from 4 to 57 percent (table 2). In 6 out of 12 cases, predicted fuel loading would be greater if d_q values from Brown were used instead of Blue Mountain data.

Specific Gravity

Specific gravities of Blue Mountain fuels were generally higher than those suggested by Brown (1974). The variation in predicted fuel loadings using s data from Brown versus s data from the Blue Mountains ranged from 2 to 44 percent (table 3).

Published data on specific gravities for small diameter fuels are decidedly lacking. Brown (1974) cited data from two known sources. Data from Beaufait et al. (1975), as cited in Brown (1974), were used for comparison because they included the greatest amount of data in common with this study. In both studies, specific gravity was based on an air-dry volume and an ovendry weight. Volumes for the data reported in Brown (1974) were determined by a

Table 2--*Comparison of Blue Mountain squared quadratic-mean fuel diameters (d_q^2) with values suggested by Brown (1974)*

Species	Diameter class	Blue Mountains d_q^2	Brown[1/] d_q^2	Difference[2/]
	Inches	- - - Square inches - - -		Percent
Douglas-fir/ Grand fir	0-1/4	0.0143	0.0122	17
	1/4-1	.230	.304	-24
Western larch	0-1/4	.0216	.0149	45
	1/4-1	.181	.238	-24
Lodgepole pine	0-1/4	.0178	.0201	-11
	1/4-1	.221	.344	-36
Ponderosa pine	0-1/4	.0356	.0342	4
	1/4-1	.262	.238	10
Subalpine fir	0-1/4	.0167	.0122	37
	1/4-1	.208	.304	-32
Engelmann spruce	0-1/4	.0192	.0122	57
	1/4-1	.280	.304	-8

[1/] Values from table 2, Brown (1974).

[2/] $\frac{\text{Blue Mountain - Brown}}{\text{Brown}} \times 100$.

Englemann spruce intercepts were greater than Brown and Roussopoulos (1974) had found; but for lodgepole pine they were less. For intercepts greater than one-fourth inch, Brown and Roussopoulos' d_q's generally were greater. In all but one case where d_q was not significantly different, the variance was significantly different, a further indication that the populations are different.

The effect of differences in the two diameter distributions on predicted loadings was determined by calculating the quadratic mean diameters for the Blue Mountain data and comparing them to the quadratic mean diameters reported by Brown and Roussopoulos (1974) and Brown (1974). Use of the Blue Mountain dq^2 values instead of those suggested by Brown (1974) would result in calculated fuel loading differences ranging from 4 to 57 percent (table 2). In 6 out of 12 cases, predicted fuel loading would be greater if dq values from Brown were used instead of Blue Mountain data.

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Ponderosa pine	0-1/4	.0356	.0342	4
	1/4-1	.262	.238	10
Subalpine fir	0-1/4	.0167	.0122	37
	1/4-1	.208	.304	-32
Engelmann spruce	0-1/4	.0192	.0122	57
	1/4-1	.280	.304	-8

[1/] Values from table 2, Brown (1974).

[2/] $\frac{\text{Blue Mountain - Brown}}{\text{Brown}} \times 100$.

Table 3--*Comparison of Blue Mountain fuel specific gravities with values suggested by Brown (1974)*

Species	Diameter class	Specific gravity[1/]		Difference[3/]
		Blue Mountains	Brown[2/]	
	Inches			Percent
Douglas-fir	0-1/4	0.61	0.55	11
	1/4-1	.62	.43	44
Grand fir	0-1/4	.58	--	--
	1/4-1	.50	--	--
Western larch	0-1/4	.54	.46	17
	1/4-1	.54	.55	-2
Lodgepole pine	0-1/4	.56	.49	14
	1/4-1	.56	.41	37

[1/] Based on air-dry volume and ovendry weight.

[2/] Values from table 4, Brown (1974).

[3/] $\frac{\text{Blue Mountain - Brown}}{\text{Brown}} \times 100$.

similar mercury displacement technique.[5/] Differences between the data cited in Brown (1974) and those from the Blue Mountains may be due to differences in the size class range of the particles reported by Brown. Also, wood volume decreases below the fiber saturation point. Volumes used to calculate specific gravities may vary between the two data sets because of differences in moisture content. Sample twigs in this study had moisture contents ranging from 7 to 10 percent. Other possible sources of differences may have been resin deposits in and bark content of sample twigs. The bark on the majority of these samples was intact when volume was determined.

Fuel Loading

Because both d_q^2 and s enter into the calculation of fuel loading, the results of this investigation have possible significance for future fuel inventories in the Blue Mountains. When bias occurs in estimated values of both d_q^2 and s, errors in prediction are compounded and can become quite large. The combined effect of applying the most suitable d_q^2 and s values in Brown (1974) to Blue Mountain fuel inventories results in prediction errors as high as 70 percent for 0- to 1.4-inch western larch twigs (table 4). In the case of 1/4- to 1-inch Douglas-fir, the greater d_q^2 and lower s values from Brown (1974) tend to offset each other, thereby reducing the percent error. In 9 out of 14 cases, Brown's (1974) values for d_q^2 and s would predict lower fuel loadings than Blue Mountain values.

Heat of Combustion

Higher heating values (table 5) are similar to those reported by Corder (1973). If a constant heat of condensation of 543 Btu/lb of wood is assumed for the water formed as a product of combustion (Byram 1959), the lower heat of combustion values range from 8,114 Btu/lb for 1/4- to 1-inch grand fir to 8,564 Btu/lb for 0- to 1/4-inch western larch twigs. These values are within 7.2 percent of the 8,000 Btu/lb value

[5] William R. Beaufait. 1977. Personal conversation. U.S. Dep. Agric., For. Serv., Region 1, Missoula, Mont.

Table 4--*Difference in predicted fuel loading between squared quadratic-mean diameter (d_q^2) and specific gravity (s) data from the Blue Mountains and from Brown (1974)*

Species	Blue Mountains				Brown			Percent difference
	Diameter class	d_q^2	s	$d_q^2 \cdot s$	d_q^2 [1]	s [2]	$d_q^2 \cdot s$	$d_q^2 \cdot s$ [3]
	Inches	Square inches			Square inches			
Douglas-fir	0-1/4	0.0143	0.61	0.0087	0.0122	0.55	0.0067	30
	1/4-1	.230	.62	.1426	.304	.43	.1307	9
Grand fir	0-1/4	.0143	.58	.0083	.0122	.55	.0067	24
	1/4-1	.230	.50	.1150	.304	.43	.1307	-12
Western larch	0-1/4	.0216	.54	.0117	.0149	.46	.0069	70
	1/4-1	.181	.54	.0977	.238	.55	.1309	-25
Lodgepole pine	0-1/4	.0178	.56	.0100	.0201	.49	.0098	2
	1/4-1	.221	.56	.1238	.344	.41	.1410	-12
Ponderosa pine	0-1/4	.0356	[2].41	.0146	.0342	.41	.0140	4
	1/4-1	.262	[2].51	.1336	.238	.51	.1214	10
Subalpine fir	0-1/4	.0167	[2].41	.0068	.0122	.41	.0050	36
	1/4-1	.208	[2].40	.0832	.304	.40	.1216	-32
Engelmann spruce	0-1/4	.0192	[2].34	.0065	.0122	.34	.0041	59
	1/4-1	.280	[2].34	.0952	.304	.34	.1034	-8

[1] Values from table 2, Brown (1974).

[2] Values from table 4, Brown (1974).

[3] $\frac{\text{Blue Mountain - Brown}}{\text{Brown}} \times 100$.

Table 5--*Heat of combustion for some Blue Mountain fuels*
(In British thermal units per pound)

Species	Higher heat of combustion		Lower heat of combustion	
	Size class		Size class	
	0 to 1/4 inch	1/4 to 1 inch	0 to 1/4 inch	1/4 to 1 inch
Douglas-fir	8,819	8,727	8,276	8,184
Grand fir	8,738	8,657	8,195	8,114
Western larch	9,117	9,103	8,574	8,560
Lodgepole pine	8,839	8,875	8,296	8,332

used as a standard in the National Fire Danger Rating System fuel models (Deeming and Brown 1975) and in mathematical models of fire behavior (Albini 1976). Western larch appeared to have a higher percentage of bark than the other samples, which probably contributed to the higher energy content. The higher heat of combustion for the composite litter and duff samples was 5,421 Btu per pound. This was low compared with heat content of woody fuels. The higher oxidation state and the presence of inorganic substances in the litter and duff were probable causes for the lower heat content.

CONCLUSIONS

Fuel particles are highly variable in their physical properties, even within size classes and within species. The results indicate that significant differences in predicted fuel loadings can occur, depending on the accuracy of data input into the equation. Inventories of small diameter fuels are of little use by themselves. Of greater importance is the significance of fuel bed properties to potential fire behavior. In most wildland fuel complexes, the characteristic ratio of surface area to volume is greater than 500 $feet^{-1}$ (Albini 1976). This is greater than the ratio of surface area to volume of 0- to 1/4-inch twigs. This fact results from the inclusion of needles and other small nonwoody fuels in fuel models. In fire behavior models, these finer elements are more heavily weighted than twigs.

Fuel inventory by the planar intersect method is a time-consuming process for large areas and can be justified only if the additional time required to obtain local values for d and s results in differences in fire potential. Applying fire behavior models to large areas such as is done in the National Fire Danger Rating System (Deeming et al. 1972) probably does not warrant the additional effort. Local data on fuel properties, however, may be important when fire behavior models are applied to specialized situations such as prescribed burning research. In such instances, other fuel elements such as needles and larger diameter branch wood should also be considered.

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METRIC EQUIVALENTS

English		Metric
5/9(^{o}F-32)	=	^{o}C
1 inch	=	2.540 0 centimeters
1 foot	=	0.304 8 meter
1 ounce	=	28.349 5 grams
1 pound	=	0.453 6 kilogram
1 ton per acre	=	2.241 7 metric tons per hectare
1 Btu per pound	=	2 326 joules per kilogram

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-316 April 1978

VEGETATIVE INDICATORS, SOILS, OVERSTORY CANOPY, AND NATURAL REGENERATION AFTER PARTIAL CUTTING ON THE DEAD INDIAN PLATEAU OF SOUTHWESTERN OREGON

by

Don Minore, *Principal Plant Ecologist*

and

Richard E. Carkin, *Forester*

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ABSTRACT

Natural regeneration in partially cut stands on the Dead Indian Plateau east of Ashland, Oregon, varies with soil nitrogen, overstory canopy, and associated vegetation. Overstory canopy and associated vegetation were used to calculate a predictive equation to identify problem areas before logging. Management recommendations are listed.

KEYWORDS: Regeneration (natural), logging (-regeneration, indicator plants, Oregon (Dead Indian Plateau).

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INTRODUCTION

The Dead Indian Plateau occupies an area of approximately 90,000 acres (22,400 ha) at 4,000- to 6,000-foot (1,220- to 1,830-m) elevations east of Ashland, Oregon. It is characterized by dry summers with frequent growing-season frosts, gentle topography, and generally poor forest regeneration. The severe climate and large gopher populations eliminate most conifer seedlings in many Dead Indian clearcuts. Area land managers have partially cut many stands in attempts to ameliorate the harsh plateau environment--often applying successive light cuts to the same area. Natural regeneration varies in these partially cut areas. A few stands are well stocked, but regeneration is unacceptably sparse in most stands.

We studied partially cut stands and post-harvest regeneration for several years to identify the environmental factors associated with regeneration success. Several plot sizes and sampling designs were tested, and many environmental variables were measured during 1973, 1974, and 1975. After analyzing these early results, we used an efficient sampling design to relate vegetative indicators, soils, and overstory canopy density to levels of post-harvest natural regeneration in 1976. This 1976 study is summarized here.

METHODS

In 1976, 55 stands that were partially cut before 1968 were each sampled with 80 small 1/300-acre (0.0013-ha) plots at 1/3-chain (6.7-m) intervals. These 80 plots were located in clusters of 5 along a horseshoe-shaped compass line. To be stocked, a 1/300-acre plot had to contain at least one established post-harvest seedling more than 2 years old. Regeneration stocking percent was obtained by dividing 100 times the number of stocked plots in each area by 80.

Overstory canopy density (in percent) was measured at the center of each five-plot cluster with a spherical densiometer.[1] Species and estimated diameters of the two nearest trees also were recorded at the center of each plot cluster. The 16 canopy density measurements were averaged for each sale area, and the 32 species and diameter determinations were used to calculate overstory stand composition. Slope and aspect were measured at four points on each sale area and then averaged. A radiation index was obtained by using these average slope and aspect figures with the tables of Frank and Lee.[2] Area elevation was recorded.

A single pit as deep as the C horizon or 50 inches was dug to

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[1] 25 points on the densiometer mirror were dot-counted 4 times at each center, facing 4 directions, and the sum was recorded as percent canopy density.

[2] Frank, Ernest C., and Richard Lee. 1966. Potential solar beam irradiation on slopes: tables for 30° to 50° latitude. USDA For. Serv. Res. Pap. RM-18. 116 p. Fort Collins, Colorado.

sample soils on each area. Total depth to the C horizon was then measured in the field. Soil samples were collected at 10-inch (25-cm) depth from each sale area and brought to the laboratory for analyses of silt and clay content, total nitrogen, phosphorus, potassium, calcium, magnesium, sodium, sulfate sulfur, and cation exchange capacity.

The presence of all higher plant species encountered was recorded on each sale area. After average regeneration stocking percents had been determined for all 55 areas, the areas were ranked by stocking percent--highest stocking first, lowest last. By modifying the comparative frequency technique described by Warner and Harper,[3] we then considered the top 18 areas and bottom 18 areas as two stocking groups and compared them species by species. Species differing between stocking groups by seven or more areas were chosen as indicator plants and assigned numerical values corresponding to their group differences. The procedure is illustrated in table 1. Of 93 species

Table 1--*Example of indicator species selection and value determination*[1]

Species	Number of areas present		Top minus bottom	Indicator value
	Top group (18)	Bottom group (18)		
Pinus lambertiana	13	2	+11	26
Abies magnifica var. *shastensis*	7	1	+6	--
Agastache urticifolia	1	7	-6	--
Eriophyllum lanatum	2	9	-7	8
Delphinium spp.	1	15	-14	1

[1]Species were compared by listing number of areas present in the group of 18 best-stocked sale areas against number of areas present in the group of 18 worst-stocked sale areas. Species with differences of 6 or less (*Abies* and *Agastache* here) were rejected. Species with differences of 7 or more (*Pinus*, *Eriophyllum*, and *Delphinium* here) were selected and assigned indicator values determined by relative differences in presence. Negative differences were converted to positive values by adding 15 to all differences, both negative and positive. Nomenclature follows Hitchcock, et al. (Vascular plants of the Pacific Northwest. 5 vol., illus. Seattle, Univ. Wash. Press. 1955-69) and Peck (A manual of the higher plants of Oregon. 2d Ed., 936 p., illus., Portland, Oreg. Binfords and Mort. 1961).

[3] Warner, James H., and K. T. Harper. 1972. Understory characteristics related to site-quality for aspen in Utah. Brigham Young Univ. Sci. Bull. Biol. Series XVI (2):20 p.

compared in this way, 27 differed by 7 or more between stocking groups and were selected as indicators (table 2). The 27 indicator species were used to calculate a vegetation index for each sale area by averaging the indicator values of all species present on that area.

Table 2--*Indicator species and values to be used in predicting regeneration success under partially-cut overstory stands. A vegetation index may be obtained by averaging the values of all species present on a given area*

Species	Indicator value
Castanopsis spp.	26
Pinus lamberiiana Dougl.	26
Pyrola picta (J. E. Sm.)	26
Arctostaphylos nevadensis Gray	25
Ceanothus velutinus Dougl.	25
Goodyera oblongifolia Raf.	25
Linnaea borealis L.	25
Apocynum androsaemifolium L.	24
Pyrola secunda L.	24
Chimaphila umbellata (L.) Nutt.	22
Anemone oregana Gray	8
Eriophyllum lanatum (Pursh) Forbes	8
Mitella spp.	8
Osmorhiza chilensis (Hook.) Arn.	8
Synthyris reniformis (Dougl.) Benth.	8
Achillea lanulosa Nutt.	7
Phacelia heterophylla Pursh.	7
Hydrophyllum fendleri (Gray) Hel.	6
Lathyrus nevadensis Wats.	6
Polemonium carneum Gray	6
Stellaria jamesiana Torr.	6
Vicia americana Muhl.	6
Collomia grandiflora Dougl.	5
Potentilla spp.	5
Ribes binominatum Hel.	5
Collinsia parviflora Dougl.	3
Delphinium spp.	1

Data were analyzed by stepwise multiple regression analyses. Regeneration stocking percent was the dependent variable in these analyses. Independent variables were:

elevation
aspect
slope
overstory canopy percent
vegetation index
years since sale
average overstory d.b.h.
percent white fir (*Abies concolor* Lindl. and Gord.) in overstory
percent Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in overstory

percent incense-cedar (*Libocedrus decurrens* Torr.) in overstory
percent ponderosa pine (*Pinus ponderosa* Dougl.) in overstory
percent Shasta red fir (*Abies magnifica* Murr. var. *shastensis* Lemm.) in overstory
radiation index
soil depth
silt and clay
phosphorus
potassium
calcium
magnesium
calcium/magnesium ratio
sodium
total soil nitrogen
sulfate sulfur
soil cation exchange capacity

Easily measurable variables that were significantly correlated with regeneration stocking in these analyses were used in a final multiple regression equation.

RESULTS

Even a casual observer soon notices that forest regeneration is poor in many partially cut stands on the Dead Indian Plateau. More thorough investigation, however, shows that this situation is not uniform. Some of these stands lack any noticeable post-harvest regeneration. Other stands are well stocked with young, vigorous seedlings. Most stands fall somewhere between these extremes--regeneration is present but not abundant. Post-harvest natural regeneration stocking in the 55 partially cut sample areas ranged from 3 to 76 percent as measured on the eighty 1/300 acre plots established in each area (appendix). Environmental variables significantly correlated with stocking included soil nitrogen, overstory canopy density, and vegetation.

Total soil nitrogen was negatively correlated with regeneration stocking ($r = -.465$)--high levels of soil nitrogen were associated with poor regeneration, low nitrogen levels with good regeneration. Correlation coefficients (r values) do not imply cause-and-effect relationships, and low stocking associated with high nitrogen may be the indirect result of other environmental factors rather than a nitrogen-caused phenomenon. Higher soil nitrogen levels, however, often induce vigorous, succulent seedling growth--growth that is damaged more by frost than the less succulent growth that occurs when nitrogen is less plentiful. Seedling frost damage has been observed throughout the growing season on the Dead Indian Plateau, and the negative nitrogen correlation with stocking percent may be the result of frost sensitivity induced by soil fertility.

No obvious relationship between light and regeneration is evident on the Dead Indian Plateau. With the exception of the contrast between clearcuts and partial cuts, field observations revealed only

small differences in regeneration stocking associated with overstory canopy variations on any single area; and an optimum canopy density was difficult to identify. When average stocking levels for all 55 sample areas were plotted against average canopy densities on a coordinate system, a general trend toward higher stocking levels around 60-percent canopy density became apparent (fig. 1). When expressed as canopy density deviations from 60 percent, this trend was significant in a linear correlation analysis (fig. 2). All other things being equal, a canopy density of 60 percent seems to be optimum for natural regeneration on the Dead Indian Plateau.

The vegetation index derived from species presence data was significantly correlated with regeneration ($r^2 = 0.56$). Occurrence of the 27 species used in this index was closely associated with the occurrence of tree seedlings as expressed in stocking percentages. No cause-effect relationship is implied, but factors affecting regeneration levels also affect the occurrence of plant species. The plant species thus serve as integrating indicators of the environmental complex that determines regeneration success or failure. When vegetation index and canopy density (expressed as the deviation from an optimal 60 percent) were combined in a multiple regression

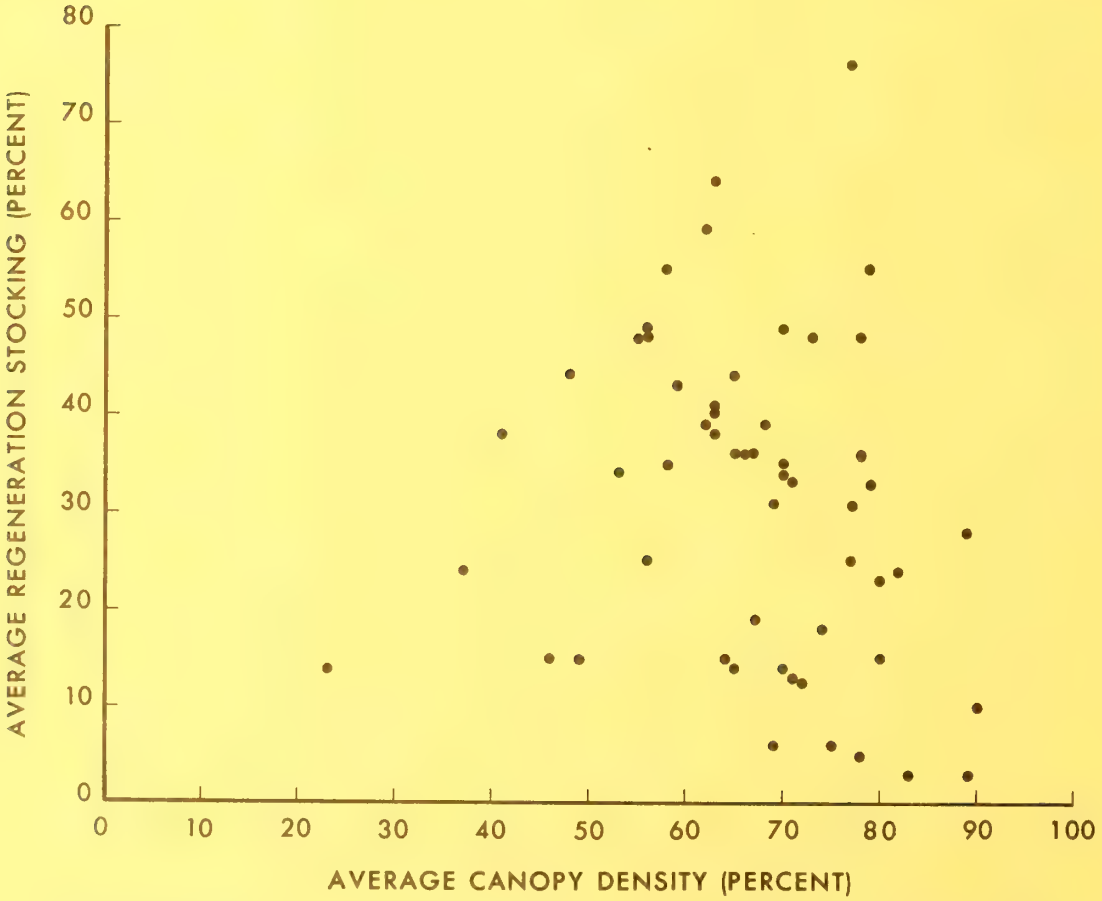

Figure 1.--Relation of average regeneration stocking to average canopy density on 55 partially cut areas.

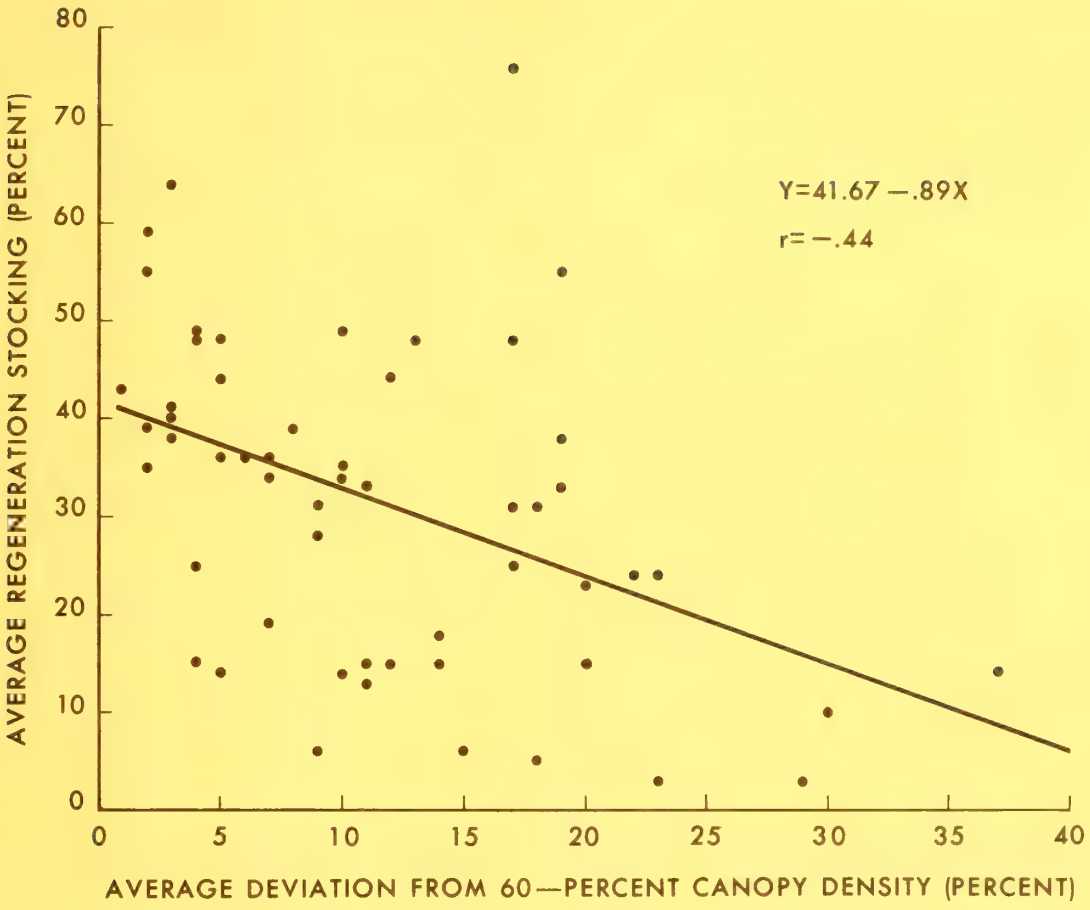

Figure 2.--Relation of average regeneration stocking to deviation from average canopy density of 60 percent.

equation, they accounted for 61 percent of the stocking variation observed among the 55 sale areas sampled in 1976:

$$\text{Stocking percent} = -5.161 + 4.753\ (\text{Vegetation Index}) - 0.09757\ (\text{Vegetation Index})^2 - 0.4938\ (\text{Deviation from 60 percent canopy})$$

$$r^2 = 0.61$$

Standard error of estimate = 10.6

Our field observations indicate that natural regeneration is adequate wherever the vegetation index is 20.0 or above.

MANAGEMENT RECOMMENDATIONS

As overstory canopy density and vegetative indicators are significantly correlated with natural regeneration success on the Dead Indian Plateau, they may be used in recommending management practices. Conditions most favorable for natural regeneration probably are also

most favorable for planted seedlings, so the following recommendations should apply to all partial cutting in the area...even when underplanting is practiced in a two-cut shelterwood system.

1. Determine a vegetation index for the area to be managed by using the plant species listed in table 2, averaging the values of species present. A minimum area of 4 acres (1.62 ha) should be examined.

2. If the vegetation index is 20.0 or above, remove enough sawtimber to create an overstory canopy density of 60 percent (60-percent crown cover, 40-percent open sky).[4] Rely on natural regeneration. Our sample of 55 partially-cut areas indicates that less than 20 percent of all stands on the Dead Indian Plateau will have vegetation indices of 20.0 or above.

3. In approximately 80 percent of all stands on the Dead Indian Plateau, vegetation indices will be less than 20.0. In these low-index stands, remove enough overstory to leave a canopy density of 60 percent, then underplant immediately. Do not depend upon natural regeneration--it will not be adequate where vegetation indices are below 20.0.

[4] In making this recommendation, it is assumed that the overstory can be removed without undue damage to established regeneration.

APPENDIX

Partial List of Variables Measured, by Sale Area

Area location	Stocking (percent)	Elevation (feet)	Overstory canopy (percent)	Vegetation index	Years since sale	Total soil N (percent)	Soil C.E.C.[1] (meq/100g)
T. 39 S. R. 3 E., sec. 21	14	5,000	23	7.5	8	.18	28.49
T. 39 S. R. 3 E., sec. 21	15	5,050	49	8.2	35	.10	26.85
T. 38 S. R. 2 E., sec. 11	13	4,950	71	7.1	9	.22	35.55
T. 38 S. R. 2 E., sec. 13	6	5,350	69	5.8	10	.20	51.44
T. 38 S. R. 3 E., sec. 30	14	5,200	65	6.9	13	.14	45.20
T. 39 S. R. 3 E., sec. 17 and 18	6	4,960	75	10.2	14	.09	47.47
T. 38 S. R. 3 E., sec. 13	33	4,650	79	11.4	10	.15	32.54
T. 38 S. R. 4 E., sec. 19	25	4,650	56	5.9	10	.13	32.17
T. 38 S. R. 4 E., sec. 7	24	4,680	37	11.1	14	.20	38.40
T. 38 S. R. 4 E., sec. 26	48	5,600	55	14.9	12	.13	35.93
T. 38 S. R. 3 E., sec. 11	15	4,500	64	11.1	7	.10	36.62
T. 38 S. R. 3 E., sec. 21	25	4,700	77	8.6	18	.14	41.35
T. 38 S. R. 3 E., sec. 13	23	4,640	80	8.5	21	.17	34.80
T. 38 S. R. 3 E., sec. 13	36	4,680	66	7.9	9	.11	34.42
T. 38 S. R. 4 E., sec. 27	39	5,100	68	21.7	12	.06	23.82
T. 39 S. R. 3 E., sec. 27	34	5,000	53	13.4	6	.12	32.76
T. 38 S. R. 3 E., sec. 25	39	4,700	62	14.1	6	.13	30.48
T. 38 S. R. 3 E., sec. 35	35	4,800	58	12.6	13	.07	38.15
T. 39 S. R. 4 E., sec. 19	36	4,800	78	19.2	11	.10	30.50
T. 39 S. R. 3 E., sec. 25	38	5,000	63	15.5	23	.06	65.14
T. 39 S. R. 3 E., sec. 23	31	5,560	69	10.4	14	.12	31.25
T. 39 S. R. 3 E., sec. 14	24	5,440	82	9.0	14	.16	39.68
T. 39 S. R. 3 E., sec. 11	33	5,500	71	11.4	7	.12	48.87
T. 39 S. R. 4 E., sec. 9	55	4,600	79	15.9	9	.07	39.36
T. 39 S. R. 4 E., sec. 17	35	5,300	70	16.1	10	.11	54.29
T. 39 S. R. 5 E., sec. 3	43	5,550	59	15.3	11	.11	25.60
T. 38 S. R. 5 E., sec. 33	64	4,800	63	24.9	6	.05	30.50
T. 39 S. R. 3 E., sec. 26	36	5,700	65	14.1	12	.18	36.41
T. 39 S. R. 6 E., sec. 5	76	5,050	77	23.3	34	.11	28.57
T. 38 S. R. 6 E., sec. 29	49	5,300	56	24.6	24	.07	24.06
T. 38 S. R. 6 E., sec. 29	44	5,200	48	24.8	10	.06	26.53
T. 38 S. R. 5 E., sec. 34	38	6,040	41	13.8	4	.14	33.56
T. 38 S. R. 5 E., sec. 25	48	5,350	56	16.4	9	.14	24.81
T. 38 S. R. 5 E., sec. 30	59	5,100	62	22.8	13	.11	32.86
T. 39 S. R. 6 E., sec. 5	40	5,150	63	24.8	13	.06	25.61
T. 38 S. R. 3 E., sec. 15	41	4,600	63	11.1	10	.09	38.23
T. 38 S. R. 3 E., sec. 9	44	4,550	65	10.8	13	.04	41.53
T. 39 S. R. 3 E., sec. 5	5	5,800	78	5.9	10	.21	51.02
T. 39 S. R. 3 E., sec. 9	15	5,450	46	7.3	12	.12	40.49
T. 38 S. R. 3 E., sec. 33	19	5,400	67	6.9	13	.06	29.91
T. 38 S. R. 3 E., sec. 11	31	4,400	77	8.8	10	.14	41.78
T. 39 S. R. 3 E., sec. 7	36	5,250	67	6.1	11	.07	37.75
T. 39 S. R. 4 E., sec. 5	49	4,650	70	14.8	26	.14	31.15
T. 38 S. R. 4 E., sec. 35	55	4,750	58	20.7	12	.06	22.35
T. 39 S. R. 4 E., sec. 15	48	4,400	73	20.8	26	.14	27.89
T. 39 S. R. 3 E., sec. 30	14	4,800	70	5.9	12	.19	41.51
T. 39 S. R. 4 E., sec. 23	3	3,950	83	10.5	9	.08	22.81
T. 38 S. R. 3 E., sec. 32	15	5,750	72	7.8	15	.11	27.34
T. 38 S. R. 5 E., sec. 28 and 33	18	5,000	74	24.8	6	.24	30.68
T. 39 S. R. 6 E., sec. 7	48	5,800	77	19.0	11	.07	39.47
T. 39 S. R. 3 E., sec. 32	3	4,800	89	8.4	15	.09	47.79
T. 39 S. R. 3 E., sec. 34	28	5,050	89	8.4	15	.13	33.46
T. 39 S. R. 3 E., sec. 3	10	5,080	90	9.4	14	.23	37.70
T. 39 S. R. 3 E., sec. 23	34	5,600	70	12.6	7	.13	42.21
T. 39 S. R. 3 E., sec. 6	15	5,600	80	6.0	11	.17	51.02

[1] C.E.C. = cation exchange capacity.

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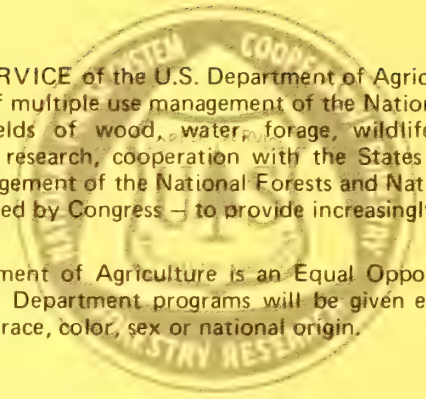

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USDA FOREST SERVICE RESEARCH NOTE

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ORIGIN AND DEVELOPMENT OF VEGETATION AFTER SPRAYING AND BURNING IN A COASTAL OREGON CLEARCUT

by

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Abstract

Numbers of brush resprouts and seedlings increased following spraying and burning on north and south aspects in one clearcut in the Oregon Coast Ranges. A release spray applied 3 years after burning reduced shrub but not herbaceous cover. The study suggests that good control of residual vegetation after logging and prompt reforestation are essential in brush-threat areas of the Coast Ranges.

KEYWORDS: Site preparation (-regeneration, revegetation, herbicides (-regeneration, fire use, succession, Oregon (Coast Ranges).

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FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

INTRODUCTION

Conifer and mixed conifer-hardwood stands in the Oregon Coast Ranges often have a well-developed understory of shrub species such as salmonberry[1], vine maple, red huckleberry, and salal and herbs such as western springbeauty, bleeding heart, and swordfern that remain after logging. Dense shade cast by this ground cover prevents drying of logging slash and reduces effectiveness of broadcast burning (Williams 1964). Aerial spraying of herbicides prior to burning to reduce shade and increase the amount of fine fuels is rapidly becoming standard practice following clearcutting in the Coast Ranges.

Sprayed areas can often be burned under marginal conditions making fire control easier (Bentley et al. 1971, Carpenter et al. 1970, Green 1970). Desiccation of woody vegetation with herbicides markedly influences fire behavior--more than can be attributed to changes in fuel moisture content alone (Bentley et al. 1971). Fires in sprayed brush build up and spread over an area more rapidly and uniformly than do fires in unsprayed brush (fig. 1). If, however, weather conditions are not favorable for drying or if burning is done too soon after spraying even a spray that kills the brush cannot assure a good burn (Ryker 1966).

Much is known about the influence of burning on development of vegetation on clearcuts or in brushfields (Dyrness 1973, Gratkowski 1961 and 1965, Isaac 1940, Morris 1970, Steen 1966, Yerkes 1960). Few of the existing studies, however, concern cuttings in the Coast Ranges; and only one examines response to spraying and burning (Gratkowski 1961 and 1965). Knowledge of origin of vegetation following site preparation is important in developing silvicultural practices that minimize establishment of undesirable species. Origin of brush species after fire has been studied in chaparral types of California and southwestern Oregon (Gratkowski 1961 and 1974, Horton and Kraebel 1955, Sampson 1944, Stone and Juhren 1951) but is unknown for most coastal species.

Figure 1.--Fires in sprayed brush build up and spread rapidly and uniformly.

A field study was initiated during 1972 to determine the origin and development of vegetation after spraying and burning in the central Oregon Coast Ranges. This study measured changes in vegetation before and after spraying and burning and after application of herbicides to release planted Douglas-firs on one clearcut.

[1]Scientific names of species mentioned are tabulated at the end of the report.

METHODS

A 40-acre (16.19 ha) clearcut logged during late winter and early spring of 1972 near Cannibal Mountain (SE1/4 Sec. 21, T. 14 S., R. 10 W., Western Meridian) in the Waldport Ranger District of the Siuslaw National Forest, Oregon, was selected for study. About 86 percent of the volume removed was Douglas-fir, 10 percent was red alder, and 4 percent was western hemlock.

The cutting was aerially sprayed in late July with 2 pounds (2.24 kg/ha) acid equivalent (ae) of low volatile esters of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) in an oil-in-water emulsion carrier containing 0.5 gallon (4.7 l/ha) of diesel oil, 8 gallons (84 l/ha) of water, and 0.5 pound (0.56) kg/ha) of Vistick spray thickener per acre. The area was then broadcast burned in late September, 2 months after spraying, and planted with 2-0 Douglas-fir in February of 1973. An aerial spray containing 3 pounds (3.36 kg/ha) ae of low volatile esters of 2,4,5-T in 8.25 gallons (77.1 l/ha) of water per acre was applied in August of 1975, 3 years after burning, to release the plantation from competing vegetation. Rain, falling shortly after application of the release spray, reduced the effectiveness of the herbicide and resulted in a low degree of brush control.

An intermittent stream divided the cutting into north- and south-facing slopes. Five randomly located 100-foot (30.5-m) line intercepts were established on both slopes to estimate ground cover before burning (August 1972), 1 year after burning (July 1973), 3 years after burning and just before release spraying (June 1975), and 4 years after burning and 1 year after release spraying (August 1976). The before-burning sample was obtained about 2 weeks after spraying, before herbicide-induced wilting had occurred. Length of live crown intercept of each species, projected onto 2.5-foot (0.76-m) high sample lines, was measured to the nearest 0.1 foot (3 cm) and percentage cover calculated using a method described by Canfield (1941). Transects were oriented down the prevailing slope and located according to a systematic random survey using different starting points for each examination.

Numbers of original or resprouting stems and new seedlings of all brush species were counted on five 1-milacre (0.001-acre or 0.0004-ha) circular plots located at 20, 40, 60, 80, and 100 feet (6.1, 12.2, 24.4, 30.5 m) along each intercept before and 1 year after burning. Plant origin was determined by uprooting all stems in each 1-milacre sample. Seedlings were distinguished by the presence of an independent root system originating from the root crown and usually by the presence of cotyledons. Plants arising from sprouts had root systems arising from buried plant parts and did not have cotyledons.

RESULTS

Changes in ground cover before and after burning and release spraying are shown in table 1; cover changes for slash, herbs, shrubs, and trees are also shown in figure 2. Total cover and relative composition were similar on north and south aspects prior to burning, although shrub cover was slightly higher on the south slope. Logging disturbance alone would not have adequately prepared the site for planting.

Spraying and burning converted the predominant cover from logging slash and salmonberry to woodland groundsel. Herbaceous cover attained a maximum by the 3d year after burning while shrub cover continued to increase. By the 3d year, shrub cover exceeded preburn levels on both north and south slopes (fig. 3). This suggests that spraying and burning delay brush development about 3 years. In some instances, this may be adequate to allow large planting stock to outgrow competing vegetation on at least a portion of the cutting.

Table 1--*Ground cover before and after burning and after release spraying on a north and south aspect in the Oregon Coast Ranges*

Species	North aspect				South aspect			
	Before burn	1 year after burn	3 years after burn	4 years after burn, 1 year after release	Before burn	1 year after burn	3 years after burn	4 years after burn, 1 year after release
	Percent of total cover							
Trees:								
Douglas-fir	0	0.03	0.60	0.40	0	0.03	0.60	2.20
Shrubs:								
Salmonberry	15.40	9.10	29.40	31.60	21.50	4.70	26.80	19.20
Thimbleberry	.20	.20	2.70	.80	0	.80	1.70	2.30
Red huckleberry	.50	.10	.70	0	3.00	0	1.20	1.20
Red elderberry	.05	.01	1.00	.60	0	.02	.07	0
Vine maple	1.30	.10	.10	.10	.60	0	.40	0
Salal	.70	.20	0	0	5.30	1.10	1.80	7.00
Trailing blackberry	0	0	0	0	.20	.90	2.40	.20
Other Shrub	.50	0	.10	0	.60	.07	.30	.40
Total shrub	18.65	9.70	34.00	33.10	31.20	7.60	35.30	30.30
Herbs:								
Swordfern	5.50	3.20	7.80	5.80	3.90	.80	.90	1.00
Bracken fern	0	0	.80	0	.90	3.00	12.30	25.70
Woodland groundsel	1.40	22.70	.40	1.60	2.30	41.10	1.30	1.10
Grasses	0	.20	12.20	28.90	0	.40	13.40	25.80
Other herbs	.10	1.60	18.90	5.80	.30	1.70	20.40	23.20
Total herbs	7.40	28.70	41.90	42.10	7.40	47.50	48.50	76.80
Slash:	53.60	20.00	26.80	24.80	43.90	15.40	20.30	12.30
Total cover	79.60	58.40	103.30	100.40	82.50	70.50	104.70	121.60

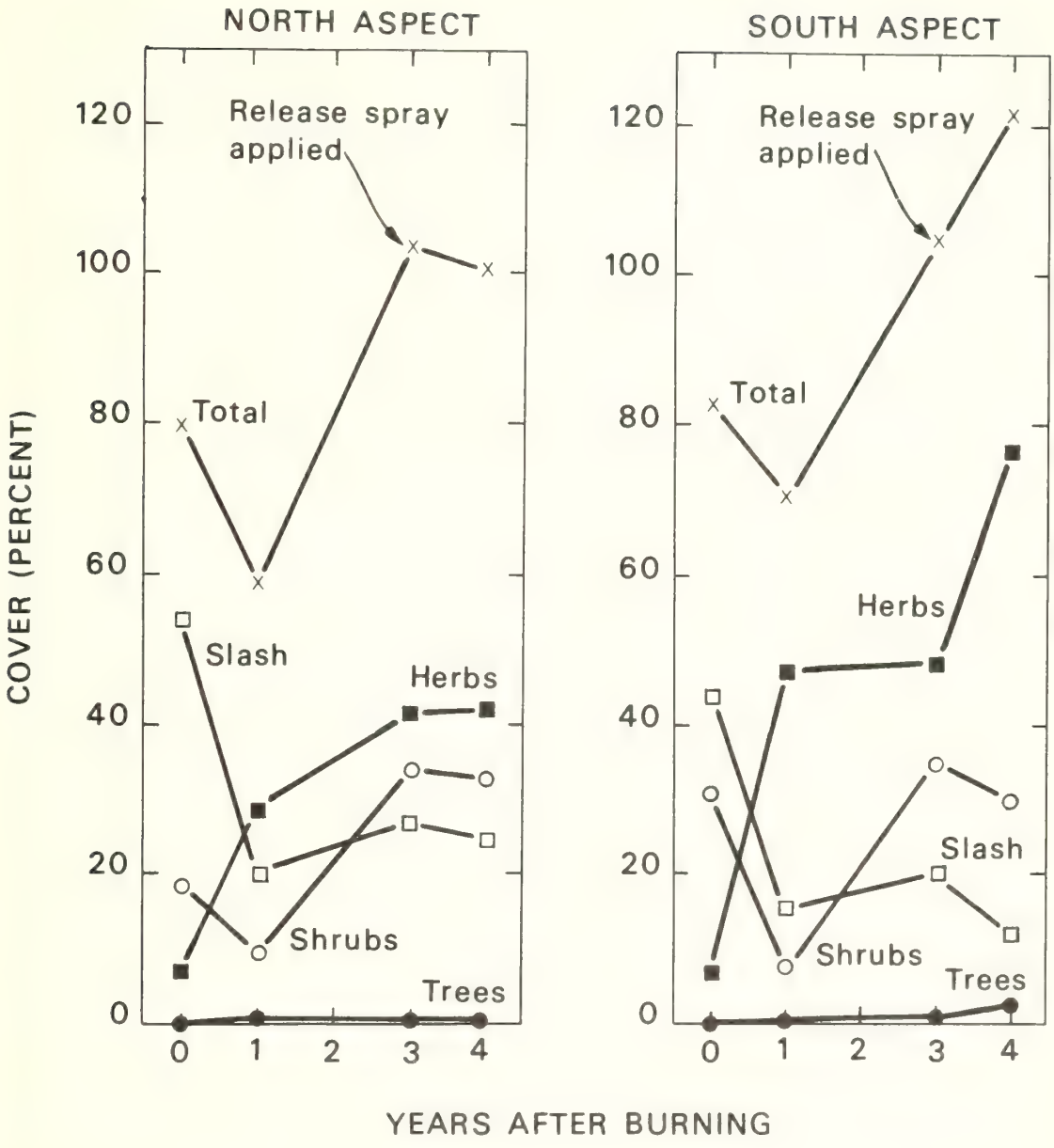

Figure 2.--Changes in ground cover before and after burning on a north and south aspect.

A

B

Figure 3.--Changes in vegetation on north (foreground) and south (background) aspects. A. Slash and salmonberry predominate after logging. B. Common groundsel predominates 1 year after burning. C. Salmonberry predominates 3 years after burning.

C

A release spray applied 3 years after burning seems to have retarded further development of the shrub component of the plant community despite the reduced effectiveness of the herbicide. Herbaceous cover on the south slope increased markedly following spraying, however. This increase was due to a doubling of bracken fern and grass cover between the third and fourth year after burning. Bracken fern and grasses are resistant to 2,4,5-T. Increases in grass cover also occurred on the north aspect after spraying but were balanced by losses in cover of other herbaceous species.

Before burning on the north aspect, 47 percent of all brush stems originated from new seedlings (table 2); on the south aspect, only 13 percent originated from seedlings. These seedlings were usually found on microsites disturbed by logging with partial or complete removal of the surface litter. Total number of seedlings before burning was lower on the south slope than on the north slope. Species composition, however, was similar except that trailing blackberry was found only on the south slope and thimbleberry on the north slope in this survey. Total number of original and resprouting stems and seedlings was 1.3 times greater on the north than on the south aspect.

After burning, 61 percent of all brush stems on the north and 50 percent on the south aspects originated from seedlings. Total brush density increased only slightly as a result of burning on the north but increased 3.5 times on the south aspect. Salmonberry was abundant on both aspects while thimbleberry was more common on the south slope. Salal, red elderberry, and trailing blackberry were found almost exclusively on the south slope after burning.

About 90 percent or more of all brush seedlings before and after burning on both aspects were salmonberry and thimbleberry. Germination of salmonberry seeds seemed to be little influenced by broadcast burning--there were about as many seedlings germinating after burning as there were before

Table 2--*Origin of brush species before and 1 year after burning on north and south aspect in the Oregon Coast Range*

Species	North aspect				South aspect			
	Before burning		1 year after burning		Before burning		1 year after burning	
	Original stems	Seedlings	Original stems & sprouts	Seedlings	Original stems	Seedlings	Original stems & sprouts	Seedlings
	Number per acre							
Trees:								
Bitter cherry	0	0	0	40	0	0	0	480
Shrubs:								
Salmonberry	10,700	6,150	7,880	5,680	10,920	2,120	10,520	3,920
Thimbleberry	0	4,450	0	8,760	0	0	200	24,640
Red huckleberry	550	0	0	0	1,200	0	1,440	0
Red elderberry	0	650	0	1,640	0	40	0	2,240
Salal	250	0	640	0	2,840	0	15,960	0
Trailing blackberry	0	0	0	0	40	200	1,520	0
Other shrubs	1,300	0	1,640	0	600	0	1,520	0
Total	12,800	11,250	10,160	16,120	15,600	2,360	31,160	31,280

burning. In contrast, germination of thimbleberry seeds seemed to be stimulated by conditions created by burning; there were 7.5 times as many seedlings following burning as there were before burning. Red elderberry seeds also appeared to be influenced by burning; seedlings were found after, but not before, burning. Neither of these species, however, contributed significantly to vegetative cover 3 or 4 years after site preparation. The data and personal observations on other cuttings suggest that the predominant shrub cover develops from resprouting of species that were present at the time of logging. The numerous brush seedlings are largely eliminated by animal browsing, competition, or other causes. Thus, the original shrub understory, perhaps of almost identical genetic makeup, with a few minor additions tends to replace itself about 3 or 4 years after burning.

The proliferation of seedlings following broadcast burning may result from removal of inhibitors or exposure of mineral soil by the fire. A study of natural seed populations suggests that most brush seed germination occurs in soil rather than in the litter (table 3). Ten 1-foot-square samples of surface litter and underlying A soil horizon to a depth of 2 inches (5 cm) were collected from a thinned second-growth Douglas-fir stand near Lakeside, Oregon on November 1, 1972, after all natural seed fall had ceased. The understory consisted of dense salmonberry with scattered red huckleberry and red elderberry. Samples were either left unheated or heated in an oven for 230 minutes at 170°F. Maximum temperatures attained were 131°F (55°C) in the litter and 129°F (53.5°C) in the soil. Litter and soil samples were then placed in separate flats in a lath house at Roseburg, Oregon and allowed to overwinter. Emergence of all species was recorded on June 28, 1973, the summer after treatment.

The results show that either fewer brush seeds occur in the litter or conditions there are not conducive to germination. Ruth (1970) found large numbers of salmonberry seedlings arising from mineral soil after removal of litter by tractor scarification. This suggests that the underlying soil has a large seed population. In contrast to brush species, herbaceous species germinated primarily from the litter layer. Woodland groundsel, a prolific seed producer and the most common invading herbaceous species on the Cannibal Mountain clearcut, was found in the Lakeside sample in large numbers in both soil and litter. Heating to about 130°F had little effect on most species but may have reduced viability of woodland groundsel seeds.

Table 3--*Emergence of seedlings from litter and soil collected under a thinned Douglas-fir stand*

Treatment	Average number per 1 foot square flat by species					
	Salmon-berry	Thimble-berry	Elder-berry	Woodland groundsel	Western springbeauty	Grass species
Litter unheated	0.4	0.4	0	32.4	0.2	0.8
Litter heated to 131°F	.2	0	0	23.0	2.0	.2
Soil unheated	5.0	2.0	.2	16.0	.4	.4
Soil heated to 129°F	3.0	2.4	.8	10.2	0	0

SILVICULTURAL IMPLICATIONS

This study suggests that resprouting of most understory brush species may reestablish the brush cover 3 to 4 years after logging, spraying, and burning in the Oregon Coast Ranges. If found to be more generally true, this rapid development suggests that burned units should be planted with large vigorous stock the first winter after burning to reduce or eliminate the need for release sprays. For preburn sprays, it is essential to use herbicides that produce a high degree of control of resprouting and then allow enough time between spraying and burning to permit translocation of the chemical to the roots in order to obtain maximum effect of the herbicide. Recent small-scale aerial spray tests suggest that a budbreak spray of 1/2 to 3/4 gallon per acre (4.7 to 7.0 liter/ha) of Tordon 155 in diesel oil followed by a late August or early September burn will reduce resprouting and the need for release sprays.

Even with good control of resprouting, some reestablishment of brush species can be expected from germination of existing seed in the soil. This will occur even in the absence of burning because logging disturbance alone is sufficient to expose suitable seed beds. Reinvasion from new seedlings will occur much more slowly than from resprouts originating from well-established root systems due to initially slower growth and high mortality of seedlings. Planted conifers probably have an advantage over small brush seedlings. If release spraying is necessary, the younger stems and less extensive root systems of seedling plants make them highly susceptible to herbicides.

This study suggests that good control of residual vegetation is essential. By minimizing disturbance and exposure of mineral soil, it may also be possible to reduce germination and establishment of new seedlings. Burning may increase the establishment of seedlings but may be necessary to reduce fire hazard or provide access for planting.

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APPENDIX I

Common and Scientific Names of Species Mentioned[1/]

Trees

Bitter cherry	*Prunus emarginata* Dougl.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Red alder	*Alnus rubra* Bong.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.

Shrubs

Red elderberry	*Sambucus racemosa* L. var. *arborescens* (T. & G.) Gray
Red huckleberry	*Vaccinium parvifolium* Smith
Salal	*Gaultheria shallon* Pursh
Salmonberry	*Rubus spectabilis* Pursh
Thimbleberry	*Rubus parviflorus* Nutt.
Trailing blackberry	*Rubus ursinus* Cham. & Schlecht.
Vine maple	*Acer circinatum* Pursh

Forbs

Bleeding heart	*Dicentra formosa* (Andr.) Walp.
Bracken fern	*Pteridium aquilinum* (L.) Kuhn var. *pubescens* Underw.
Swordfern	*Polystichum munitum* (Kaulf.) Presl
Western springbeauty	*Montia sibirica* (L.) How.
Woodland groundsel	*Senecio sylvaticus* L.

[1]Scientific and common names are those used in "Natural vegetation of Oregon and Washington" by Jerry F. Franklin and C. T. Dyrness. 1973. USDA For. Serv. Gen. Tech. Rep. PNW-8, 417 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

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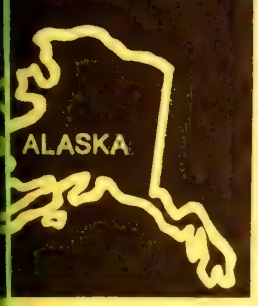

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-318

August 1978

THE RELIABILITY OF DETERMINING AGE OF RED ALDER BY RING COUNTS

by

Dean S. DeBell, Boyd C. Wilson, and Bernard T. Bormann[1]

ABSTRACT

Examination of cross-sections of 54 red alder trees from 14 stands of varying age and site conditions indicated that abnormal rings (false, partial, or missing) occur infrequently. Rings may be indistinct and ring counting must be done with great care, preferably on prepared surfaces (cross-sections or cores) and under magnification and good lighting. With such preparations, ages of red alder trees can be determined with acceptable accuracy by conventional ring-counting procedures.

KEYWORDS: Ring counts, age determination (tree/stand), red alder, *Alnus rubra*.

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INTRODUCTION

An accurate assessment of tree and/or stand age is prerequisite to many forest management decisions. Age must be known in order to use site index curves and yield tables. Moreover, many silvicultural and ecological studies involve determination of tree age.

Ages of tree species growing in temperate zones can usually be determined by counting annual rings on stem cross-sections or increment cores. Some problems may exist, however. Annual rings in diffuse-porous hardwood species are less distinct than in conifers and ring-porous hardwoods. False rings (multiple rings within a single year) may be formed, especially when growth has been checked prematurely (e.g., by drought) and then has resumed within the same growing season (Zimmermann and Brown 1971). In addition, discontinuous (partial) and missing rings have been reported in many species under certain conditions (Chapman and Meyer 1949, O'Neill 1963, Larson 1956, Oliver 1975, Stubblefield and Oliver 1978). For most species, age can be determined with acceptable accuracy if cores or stem sections are carefully prepared (e.g., planed, polished, or stained) and examined under magnification and adequate light. When false or missing rings occur, "cross-dating" techniques (Stokes and Smiley 1968, Fritts 1976) used in dendrochronology permit accurate determination of age.

Concerns about age determination in red alder (*Alnus rubra* Bong.) were raised by Smith (1973, 1978) and by Newton (1978). The indistinctness of rings in red alder (a diffuse-porous hardwood) undoubtedly contributes to these concerns. Smith (1973), for example, revised his stump age estimate of 56 years to 75 years after examining a cross-section under a binocular microscope. He also pointed out that adjacent Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) were 96 years old and considered this good evidence that at least 21 rings were missing on the alder tree. The principal concern with age determination for alder voiced by Smith (1973) and by Newton (1978), therefore, appears to be the possibility of missing rings. Smith (1978) implied that date of stand origin (i.e., years since site disturbance) or age of associated Douglas-fir trees (Smith 1973) will provide the best estimate of the age of some red alders growing on a particular site. Newton (1978) also found some evidence for missing rings on a rather old alder tree (70+ years) and has suggested that large numbers of missing rings after age 40 may compromise efforts to measure growth by stem analysis. In 1973, Smith had pointed out that present site index curves and normal yield tables (e.g., Worthington et al. 1960) may be inaccurate if missing rings are a common occurrence in this species.

Recent work near Olympia indicates that alder patches or stands are frequently younger than adjacent Douglas-fir stands and that a considerable range in age may exist in alder stands which appear even-aged.[2] Stubblefield and Oliver (1978) have examined mixed conifer/alder stands in which the alder was several years younger than associated conifers. Kennedy and Elliott (1957) and Tessier and Smith (1961) also reported substantial age variation in red alder stands sampled for some of their studies. Though our results are somewhat supported by these three other studies, such findings are at variance with commonly stated and accepted beliefs concerning establishment of this fast-growing intolerant species; that is, that alder stands are essentially even-aged and that alder trees are as old as or older than Douglas-fir associated with them in mixed stands of natural origin. To scrutinize these findings and because of the importance of the age determination question, we decided to assess the accuracy with which age can be determined by counting rings of red alder.

[2] Data on file at Forestry Sciences Laboratory, Olympia, Washington.

METHODS

Cross-sections from 111 trees which had been collected in winter 1976-77 for other research were used in this study. The trees were growing in pure alder stands on 14 sites located within a 20-mile[3] radius of Olympia. Major characteristics of these sites and stands are listed in table 1. The individual trees represented a rather wide range in age (29 to 88 years), breast high diameter (7.1 to 16.5 inches), and height (53 to 112 feet). Although most trees were dominants and codominants, some intermediate and suppressed trees were sampled (about 10 percent of total). Cross-sections from trees at the first six sites were cut just above the root collar (0 to 6 inches); cross-sections of trees on the remaining sites were cut at stump height (about 1 foot above ground).

All sections were planed for a clean, smooth surface. If annual rings were very close together (<0.02 inch), as was often the case in the outer portions of old or suppressed trees, a slanted cut was made by razor blade or gouge chisel to increase the "apparent width" of the rings. We then attempted to "date" all sections by using the technique described by Stubblefield and Oliver (1978). Essentially, this method involves locating the annual ring produced after the damaging freeze of November 1955 (Duffield 1956). Rings produced during the 1956 growing season were often much narrower and/or irregular (fig. 1). In addition, a dark brown or black line was commonly present between the 1955 and 1956 growth rings (fig. 2). Interior rot (fig. 3) or partial death of the cambium (fig. 4) was observed in a few instances. Once location of the 1956 ring was determined, we knew that 21 additional rings should exist between it and the bark. A greater number would indicate presence of false rings and a lesser number would indicate that some rings were missing. Rings were

[3] See page 7 for metric equivalents.

Table 1--*Description of sites and stands from which cross-sections of red alder were collected*

Location	Elevation	Tree age		Average height	Estimated site index[1]	Number of trees sampled
		Mean	Range			
	Feet	- - Years - - -		- - - - Feet - - - -		
Waddell Creek Road	1,000	42	41-43	78	84	4
Powderhouse Road	800	57	51-59	102	96	4
North Creek	300	53	46-56	103	100	4
Cedar Creek	400	39	32-44	94	105	4
Upper Sherman Valley	600	43	41-46	97	102	4
Lower Sherman Valley	500	55	47-63	93	84	4
McKenny	300	44	30-68	87	92	12
Porter	550	35	29-43	87	101	12
Rock Candy	900	45	31-66	82	86	12
McCleary	300	73	67-88	87	76	12
Taylor Towne	400	56	54-57	91	87	12
Schafer Park	325	54	50-60	96	93	12
Stillwater	250	59	45-69	72	67	12
Waddell Flat	400	46	44-47	2/	2/	3

[1] Based on: Norman P. Worthington, Floyd A. Johnson, George R. Staebler, and William J. Lloyd. 1960. Normal yield tables for red alder. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station Research Paper 36, 29 p. Portland, Oregon.

[2] Not available.

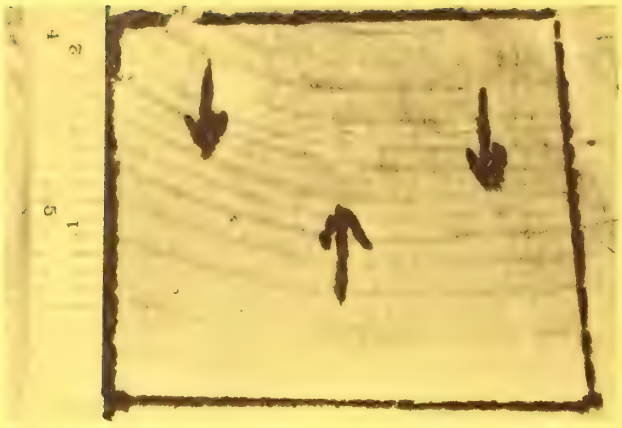

Figure 1.--A substantial reduction in width of the 1956 growth ring was common in many alder trees affected by the damaging freeze of November 1955.

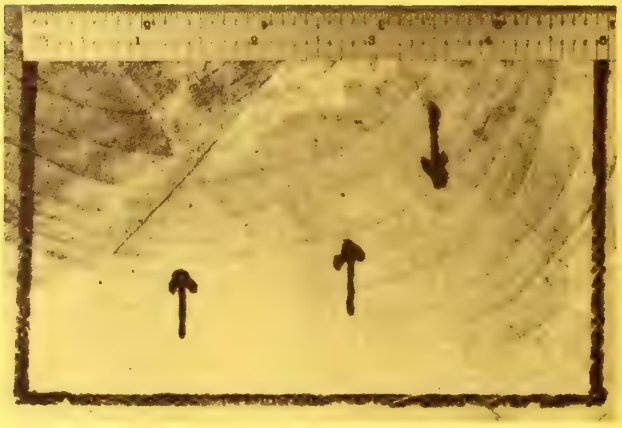

Figure 2.--Cambial growth was not reduced by the freeze in this alder, but a dark line existed between the 1955 and 1956 growth rings.

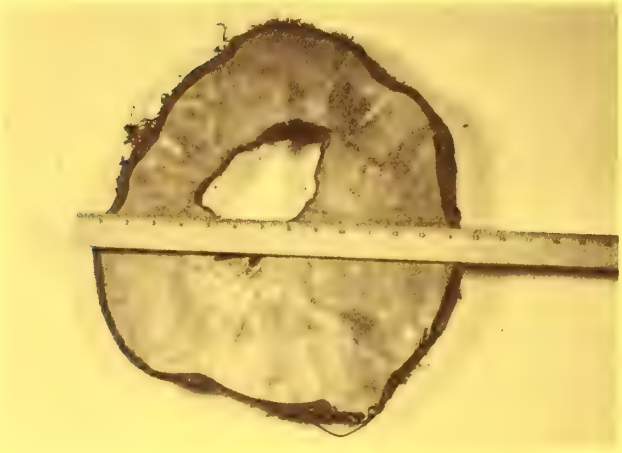

Figure 3.--Wood formed prior to the 1955 freeze contained rot in a few alder trees.

Figure 4.--The freeze resulted in partial death of the cambium of some trees.

counted with the aid of an illuminated magnifier or a dissecting binocular microscope. We were also able to check for occurrence of discontinuous rings (fig. 5) by scanning the entire section. With such data, we then could assess the probabilities of encountering false, missing, or discontinuous rings.

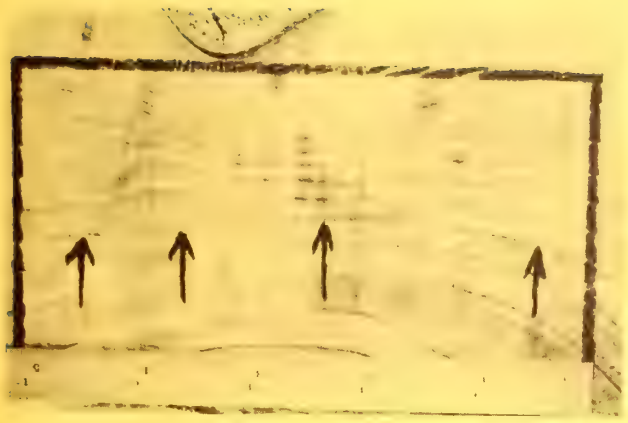

Figure 5.--Rings produced during the 1956 growing season were discontinuous and/or extremely narrowed on a few cross-sections, particularly those cut near the root-collar.

RESULTS AND DISCUSSION

We were able to locate the 1956 ring with confidence on sections from 54 trees (49 percent of all trees sampled). Tree characteristics for these sections were similar to the population originally sampled--age (30 to 79 years), breast high diameter (8.0 to 15.0 inches), and height (53 to 112 feet). Both stump and root collar cross-sections as well as all crown classes were well represented. Some trees on every site showed effects of the 1955 freeze. Thus, it seems unlikely that the selection criterion (presence of freeze-affected tissue) essential to our procedures led to any additional biases.

Although rings were close together and indistinct on several samples, use of slanting sections and/or a binocular microscope enabled us to make ring counts on all 54 sections with observable freeze damage.

Results of our ring examinations are listed in table 2. The correct number of entire annual rings was observed on sections from 46 trees

Table 2--*Results of ring examination on two types of cross-sections from red alder trees on 14 sites*

Location	Type of cross section	Number of trees with				Total rings examined	Percentage of abnormal rings
		Easily identified 1956 ring	Correct number of rings (21)	Abnormal rings			
				Number	Kind		
Waddell Creek Road	Root collar	1	0	1	Missing	21	4.8
Powderhouse Road	Root collar	4	2	2	Discontinuous	84	2.4
North Creek	Root collar	4	3	1	False	84	1.2
Cedar Creek	Root collar	4	4	0		84	0
Upper Sherman Valley	Root collar	3	2	1	False	63	1.6
Lower Sherman Valley	Root collar	2	0	2	Discontinuous	42	4.8
Subtotal	Root collar	18	11	7	Abnormal	378	1.9
McKenny	Stump	6	5	1	Discontinuous	126	.8
Porter	Stump	5	5	0		105	0
Rock Candy	Stump	5	5	0		105	0
McCleary	Stump	5	5	0		105	0
Taylor Towne	Stump	3	3	0		63	0
Schafer Park	Stump	6	6	0		126	0
Stillwater	Stump	3	3	0		63	0
Waddell Flat	Stump	3	3	0		63	0
Subtotal	Stump	36	35	1	Abnormal	756	.1
Total	Root collar and stump	54	46	8	Abnormal	1,134	.7

(85 percent). False rings were found on two trees; discontinuous or partial rings were found on five trees; and a ring was missing on one tree.

Of the eight trees with some type of abnormal ring growth, only one involved a typical section cut at stump height. In this case, the 1956 annual ring was discontinuous. The other seven trees had been examined via root collar sections. Apparently ring production is more irregular in the fluted basal section near ground level. Only eight abnormal rings (i.e., from the standpoint of age determination) were encountered in our examination of a total of more than 1,100 rings (0.7 percent). Considering only sections collected at stump height, we found only one abnormal ring in a total of nearly 800 examined rings (0.1 percent). Therefore, errors in age determination of red alder caused by abnormal rings appear to be relatively insignificant, especially for dominant and codominant trees at ages similar to those sampled in this study.

In view of these findings, we do *not* recommend using the years since site disturbance or age of adjacent Douglas-fir to estimate age of red alder. Our work (see footnote 2) and that of Tessier and Smith (1961) and Stubblefield and Oliver (1978) has shown that alder can be younger and sometimes more variable than adjacent conifers. Such age discrepancies probably result from differences in coincidental timing of abundant crops of viable seed and favorable seed bed and climatic conditions for establishment of the various species. Using years since site disturbance or conifer age to estimate alder age may lead to erroneous interpretations and conclusions regarding the formation, structure, and development of alder and mixed alder-conifer stands.

We do concur with Smith (1978) in that comparing alder ages with age since disturbance or age of adjacent or associated conifers is desirable, however. If ages differ greatly for no apparent reason, one may want to recheck ring counts on both alder and conifers.

CONCLUSIONS AND RECOMMENDATIONS

Our work suggests that missing, discontinuous, and false rings are negligible problems in determining the correct age of alder trees less than 80 years old. Indistinctness and closeness of rings in some trees appear to be far more serious problems and make counting rather difficult. To minimize such problems, we recommend the following procedures:

1. Sample only dominant and vigorous codominant trees.

2. Cut disks at stump height (stay above the fluted basal section) or breast height (if interested primarily in breast-high age).

3. Plane disk to obtain a smooth surface.

4. If rings are very closely spaced, make a slanted cut with razor blade or gouge chisel to increase "apparent ring width."

5. Apply water or petroleum jelly (Oliver 1975) to the surface to enhance ring visibility.

6. Provide good lighting and magnification.

We recognize that many foresters have neither the time or the need to use the above methods which are rather time consuming. In view of the limited number of abnormal rings found in our study, counts made carefully on increment cores extracted at breast height (and properly adjusted for years needed to attain that height) should also provide a reliable assessment of age. We recommend making a smooth razor cut along one or two sides of the core while it is still moist. Color will begin to develop (caused by oxidation of phenols) in less than one-half hour. Rings are most easily read before the core is completely dry. Ages can be substantiated by counting rings on more than one core per tree or on more than one side of each core and by

checking counts against some reference year (e.g., the 1955 freeze), or by other cross-dating techniques (Stokes and Smiley 1968).

METRIC EQUIVALENTS

1 inch = 2.54 centimeters
1 foot = 0.305 meter
1 mile = 1.609 kilometers

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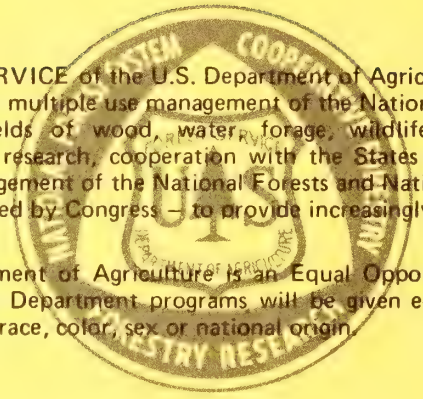

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USDA FOREST SERVICE RESEARCH NOTE

PNW-319

September 1978

RESPONSE OF A POLE-SIZE PONDEROSA PINE STAND TO NITROGEN, PHOSPHORUS, AND SULFUR

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by

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Principal Research Soil Scientist

Abstract

Fertilization with nitrogen alone, nitrogen plus phosphorus, nitrogen plus sulfur, and nitrogen plus phosphorus plus sulfur increased growth of volume, basal area, and bole area for the first 4 years after application. Application rates were 200, 100, and 30 pounds per acre for nitrogen, phosphorus, and sulfur, respectively. The effect of sulfur and phosphorus in increasing volume and bole area growth was not clear. The treatment with all three elements produced the greatest increase in basal area.

KEYWORDS: Nitrogen fertilizer response, fertilizer response (forest tree), phosphorus, sulphur, pole-stage stands.

METRIC EQUIVALENTS

1 pound/acre = 1.121 kilograms/hectare
1 acre = 0.405 hectare
1 foot = 0.304 8 meter
1 inch = 2.54 centimeters
1 square foot/acre = 0.229 568 square meter/hectare
1 cubic foot/acre = 0.069 972 cubic meter/hectare
1 mile = 1.61 kilometers

INTRODUCTION

Thinning dense stands of young ponderosa pine (*Pinus ponderosa* Laws.) usually increases diameter and height growth of the remaining trees and raises production of marketable wood under current utilization standards (Barrett 1973). Complete removal of understory vegetation also accelerated growth of young ponderosa pine in one central Oregon study, presumably by increasing the availability of water (and nutrients) to the trees (Barrett 1970).

Several studies show that some ponderosa pine stands will respond to fertilization (Mosher 1960; Wagle and Beasley 1968; Agee and Biswell 1970; Barrett and Youngberg 1970; Cochran 1973, 1977; Youngberg 1975). Much of the increased wood growth seems to result from nitrogen (N), but sulfur (S) and phosphorus (P) may be important on some sites (Will and Youngberg 1978).

This 4-year study was initiated in 1972 to determine how fertilization with N alone and with S and P changes growth of ponderosa pine stands which have been previously thinned.

METHODS

Study Area

The study site is located on the Deschutes National Forest 15 miles[1/] south of Bend, Oregon. Elevation is about 4,000 feet, annual precipitation is approximately 20 inches, and summers are usually dry. Topography in the study area slopes south and west 2 to 17 percent. The soil, a Typic cryandept (Shanahan series) developing on Mazama pumice, has a sandy loam A1 horizon 2 inches thick and a sandy loam AC horizon 21 inches thich overlying an older buried loam (table 1). Predominant understory vegetation consists of bitterbrush (*Purshia tridentata* (Pursh) DC.), needlegrass (*Stipa occidentalis* Thurb. ex Wats.), and fescue (*Festuca idahoensis* Elm.), with some manzanita (*Arctostaphylos patula* Greene) and snowbrush (*Ceanothus velutinus* var. *velutinus* Dougl. ex. Hook).

The area was railroad logged in 1927, and the present stand was 39 years old at breast height (bh) when the study was initiated. The site index (Barrett 1978) varies from 90 to 108 over the study site. The stand was thinned to an overall average spacing of about 14 feet (222 trees per acre) in 1963 and a few scattered overstory remnants were removed in the winter of 1970-71. Saving vigorous appearing, well-formed potential crop trees visibly free of mistletoe had priority over maintaining a uniform spacing in the thinning operation; therefore, tree spacing varies widely over the area (table 2).

Plot Selection and Measurements

Twenty-five 0.4-acre square areas were located to provide 0.1-acre square plots with 33-foot buffer strips. When roads, treeless openings, and stumps

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[1/] Metric equivalents are on front cover.

Table 1--*Some properties of the Shanahan soil at the study site in the Deschutes National Forest, Oregon.*[1/]

Horizon	Depth	Bulk density	Sand	Silt	Clay	<2 mm gravel	pH	P	B	S	Total N	O.M.[2/]	Extractable cations				C.E.C.[3/]
													K	Ca	Mg	Na	
	Inches	g/cm^3	- - - - Percent- - - - -					- - p/m - -			- Percent -		- - - - - - Meq/100 g - - - - - - -				
A1	0- 2	0.74	71.0	18.4	10.6	3.2	6.2	19	0.25	<0.20	0.13	9.90	0.66	5.3	0.76	0.10	12.0
AC	2-23	.94	68.0	20.0	12.0	2.9	6.6	6	.13	.60	.04	1.54	.53	3.5	.63	.10	10.2

[1/]The hydrometer method was used for the mechanical analysis of the sieved fraction less than 2 mm in size. Chemical analyses were performed by the Oregon State University soil testing laboratory, Corvallis, by its methods (Roberts et al. 971).

[2/]O.M. = organic matter.

[3/]C.E.C. = cation exchange capacity.

Table 2--*Initial ranges in some stand characteristics for the five 1/10-acre plots randomly assigned to each treatment*

Treatment[1/]	Trees	Volume	Basal area	Bole area[2/]	Average height	Average cylindrical form factor
	Number per acre	Cubic feet per acre	- Square feet per acre -		Feet	
Control	130-320	797-1,816	58.4-124.4	6,209-13,886	36.9-46.5	0.3402-0.3700
N	110-250	668-1,656	48.7-115.9	4,895-12,138	37.9-42.5	.3321- .3594
NP	140-220	738-1,552	62.7- 98.1	6,119-11,784	33.1-42.1	.3429- .3663
NS	150-200	857-1,691	67.4-109.6	7,309-11,769	37.3-42.9	.3389- .3649
NPS	130-340	906-1,615	61.9- 99.6	6,999-11,380	32.7-43.4	.3201- .3720

[1/]N = nitrogen; NP = nitrogen plus phosphorus; NS = nitrogen plus sulfur; NPS = nitrogen plus phosphorus plus sulfur.

[2/]Bole area is the surface area of the bole of the tree with the bark removed. It is an approximation of the cambial surface area along the main tree stem (Lexen 1943).

of overstory removed in 1970-71 were omitted in locating the 0.4-acre areas, all the thinned area was utilized and there was no room to incorporate changes in slope or site in the study design. The plots contained a total of 458 trees; average diameter and height were 8.8 inches and 39.7 feet. Trees in each 0.1-acre plot were tagged and measured with optical dendrometers. Diameters at a 1-foot stump and at 4.5 feet (bh) and bark thickness at bh were also determined with calipers, diameter tapes, and bark gages, respectively. These measurements and Grosenbaugh's (1964) STX program were used to determine pretreatment volumes and bole areas above a 1-foot stump and total height. A modification of one of Brickell's (1970) equations was used in the STX program to determine diameter inside bark at various points along the boles as outlined by Cochran (1976).

Trees were remeasured four growing seasons after treatment; dendrometer readings were retaken from the initial directions for each tree.

Cylindrical form factors (F) were calculated for each tree before and 4 years after treatment; the cubic volume (V) above a 1-foot stump was divided by the product of the basal area at bh (a) and total height (h):

$$F = V/ah$$

Treatments

Each plot was randomly assigned one of five treatments:

Treatment	Amount (lb/acre) and element applied	Form
1 (control)	0	--
2	200 N	urea (46 percent N)
3	200 N, 100 P	urea, triple superphosphate (19.6 percent P)
4	200 N, 30 S	urea, ammonium sulfate (21 percent N, 24 percent S)
5	200 N, 100 P, 30 S	urea, triple superphosphate, ammonium sulfate

The triple superphosphate also contained 12 percent calcium (Ca) and 1 percent S. Application of Ca to the soil does not produce responses from pine seedlings in the greenhouse, and the small amount of S was negligible. Balances of N, P, and S equivalent 200-100-30 pounds per acre were chosen because they appeared to be the most favorable for pine seedling growth in a greenhouse test on a soil derived from Mazama pumice (Youngberg and Dyrness 1965). Fertilizer was applied in November 1972 just before snow began to accumulate.

Statistical Analysis

Growth of volume, bole area, and basal area for the plots was subjected to analysis of covariance with initial basal area as the covariate. The adjusted means for the covariance analysis were combined with multipliers of a set of orthogonal comparisons (determined before treatment) to test these hypotheses:

1. The control grows as much as the average of the rest of the treatments.
2. Growth response from addition of N alone is as good as the average produced by additions of NP, NS, and NPS.
3. Growth response to the NPS treatment is equal to average growth response of the NP and NS treatments.
4. The NS treatment and NP treatments produce the same changes in volume growth.

Height growth and form factor changes were subjected to a standard one-way analysis of variance to test the hypothesis that treatment did not influence height growth or form factor change.

RESULTS AND DISCUSSION

As expected, no tree mortality occurred during the 4-year study. Volume, basal area, and bole area growth were increased significantly by all combinations of fertilizers. Fertilization with N alone caused increases in adjusted treatment means of 34 percent for volume growth, 23 percent for basal area growth, and 20 percent for bole area growth (table 3, fig. 1). Combining S or P with N

Table 3--*Adjusted means of volume, basal area, and bole area growth determined from covariance analysis and treatment means of height growth and form factor change determined from 1-way analysis of variance using plot averages as observations*[1/]

Treatment[2/]	Adjusted means from covariance analysis			Treatment means	
	Volume growth per year	Basal area growth per year	Bole area growth per year	Height growth per year	Change in form factor
	Cubic feet per acre	- - - - - Square feet per acre - - - - -		Feet	
Control	56.4 a	2.6 a	318.6 a	0.8 a	-0.0127 a
N	75.7 b	3.2 b	383.2 b	1.0 a	-.0050 a
NP	78.0 b	3.5 b c	434.5 b	1.2 a	-.0085 a
NS	88.0 b	3.6 b c	460.1 b	.9 a	-.0031 a
NPS	87.7 b	4.1 b d	481.2 b	.9 a	-.0034 a

[1/] Means followed by the letter b are significantly greater than those followed by the letter a, and those followed by the letter d are significantly greater than those followed by the letter c at the 5-percent level of probability.

[2/] N = nitrogen; NP = nitrogen plus phosphorus; NS = nitrogen plus sulfur; NPS = nitrogen plus phosphorus plus sulfur.

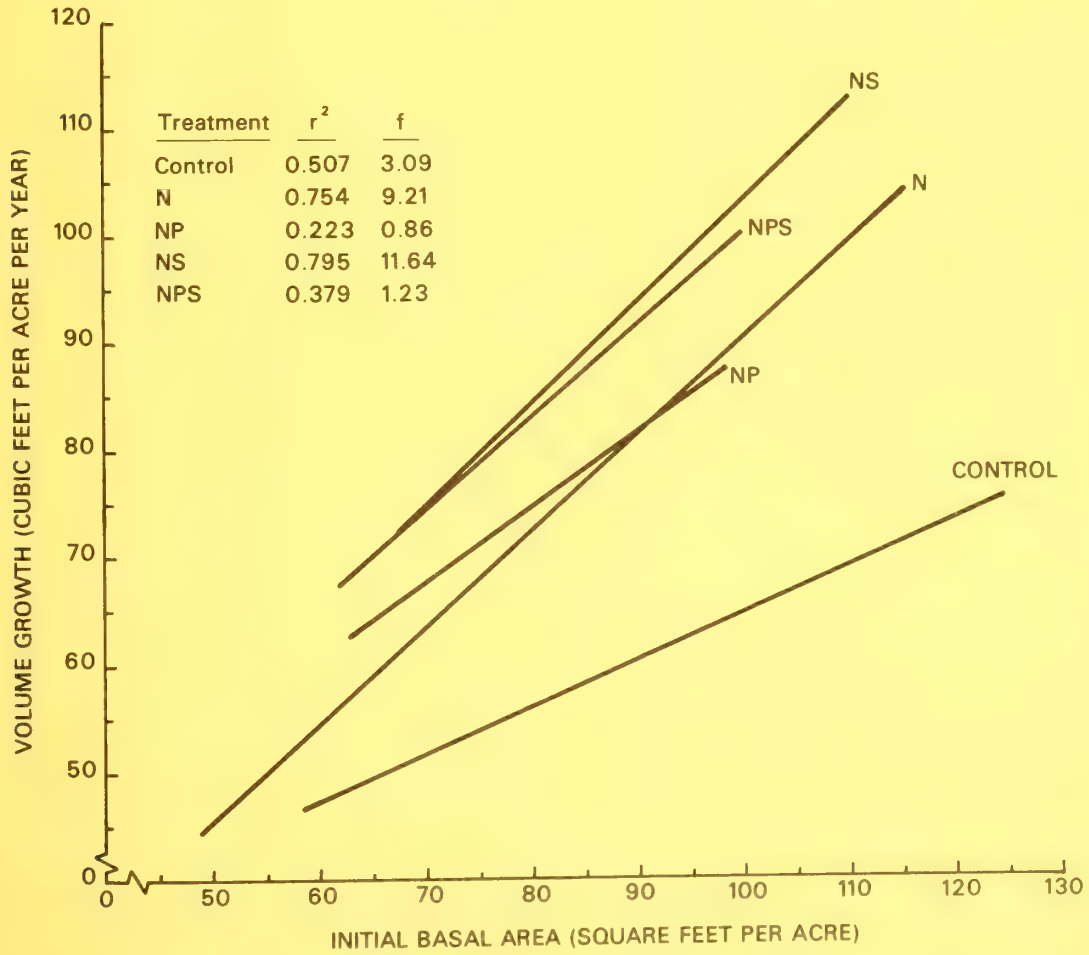

Figure 1.--Individual regressions for volume growth as a function of initial basal area. An F value of 10.13 is necessary for significance at the 5-percent level of probability. The combined regression for all treatments was significant at the 1-percent level of probability.

did not increase volume or bole area growth significantly. The NPS treatment produced significantly greater basal area growth than did the NS or NP treatment. The basal area growth rates produced by the NS and NP treatments tended to be higher than the basal area growth rates produced by N alone but were not quite significant. Bole area growth produced by the NP, NS, and NPS treatments also tended to be higher than bole area growth for the N treatment.

Fertilization did not affect height growth or the change in form factor (table 3). Although the control treatments had the lowest average height growth and the greatest change in form factor, differences did not even tend toward significance.

The increase in basal area growth with the NPS treatment over N alone, combined with a nonsignificant change in volume, height growth, or form factor, is puzzling. Basal areas can be measured precisely, but volumes and form factors depend on assumed taper relationships within bole segments. Also, stem diameters inside bark between bole segments and above bh are determined from dendrometer readings and estimates of bark thickness. Thus, estimates of basal area growth are probably more accurate than estimates of form factor change or volume and bole area growth even though every tree in the study was measured with a dendrometer.

The primary goal of fertilizing stands similar to these is production of more usable volume. Application of P and S along with N at the rates tested here did not prove justifiable; however, this study did not rule out the possible importance of S or P. Will and Youngberg (1978) found that an NPS treatment (200 lb N, 50 lb P, and 100 lb S per acre) on a Shanahan soil produced a slightly greater basal area increment the second 5-year period after treatment than the N, NP, or NS treatments. They also suspected that S increased wood production. There may be a small S effect in this study that the experiment was not sensitive enough to determine. This effect, if real, may be responsible for increasing volume production more than 10 ft^3/acre per year over the N alone treatment (fig. 1).

Published soil N values determined by the same method in other studies (Geist and Strickler 1970, Geist 1974, Tiedemann and Klock 1977, Tiedemann and Berndt 1972) and other results from nonpumice soils (Cochran 1977) indicate that 200 lb N per acre (435 lb urea/acre) will increase growth of many pine stands on nonpumice soils east of the Cascades in Oregon and Washington. Reported soil S and P values from nonpumice areas are generally higher than those found here, but the possible importance of S and P applications in other areas for increasing wood production is hard to evaluate because other soil testing methods were used at times so the results are not comparable.

Geist (1976) found S as well as N is important in increasing forested range production on volcanic ash soils in northeastern Oregon. The demonstrated increase in grass production, coupled with the possible importance of S in wood fiber production, may cause some land managers to apply S along with N to thinned ponderosa pine stands. For S plus N applications, a rate of 30 lb S per acre in the form of ammonium sulfate is suggested. Adding 125 lb of ammonium sulfate per acre will also supply 26 lb of N per acre. The extra 174 lb of N per acre needed for the recommended level can be supplied with 380 lb of urea per acre.

Growth rates of this pole-size stand for the second 4-year period will be measured to see if application of S and P along with N causes a significant increase in usable wood over a longer period. For foresters wishing to fertilize thinned stands now, these results show that 200 lb N per acre will produce a 15- to 45-percent increase in growth of thinned stands on similar soils at least for a 4-year period. These increases in growth will probably last longer than 4 years (Cochran 1977).

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GPO 986-790

USDA FOREST SERVICE RESEARCH NOTE

PNW-320 October 1978

CHARACTERISTICS OF RESIDUES IN A HELICOPTER LOGGED AREA OF OLD-GROWTH DOUGLAS-FIR

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by

W. Y. Pong, *Research Forest Products Technologist*

and

John W. Henley, *Research Forest Products Technologist*

ABSTRACT

The volume and character of residues in three old-growth Douglas-fir cutting units in the Oregon Cascades were determined before and after harvesting by helicopter and yarding of unutilized material (YUM). Two silvicultural treatments and two levels of YUM yarding were applied. Gross volumes of residues in all study units increased after logging. Yarding unutilized material appears to be effective in reducing the coarse residue and was more effective in the clearcut units than in the partial cut units. Study results indicate 65 to 80 percent of all residues generated had some potential for utilization. Specifications for yarding of unutilized material influenced the size and piece count distribution of the usable residue remaining on the study sites.

KEYWORDS: Residue surveys, slash utilization, helicopter logging, wood waste utilization.

Conversion factors are on page 33.

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

INTRODUCTION

Residue information was obtained in studies conducted by the Pacific Northwest Forest and Range Experiment Station on three timber sale areas within the Pansy Creek drainage on the Estacada Ranger District of the Mt. Hood National Forest in Oregon. These sale areas were logged using balloon, helicopter, and skyline logging systems. The aim of the studies was to evaluate the performance of the systems in attaining land management objectives. The residues left after logging are an important factor to consider when evaluating the performance of a logging system.

Logging residues are a problem continually confronting land managers who are attempting to achieve the goals and objectives of multiple-use forestry. Land managers seek to manage logging residues to achieve optimum utilization of the resource, to minimize the risk of fire, and to achieve rapid regeneration in a manner that meets a wide range of environmental requirements. Information on the amounts and characteristics of residues generated by various logging systems is an important factor in decisions between alternative courses of action. This report, based on a case study, provides information on the quantities and characteristics of residues left in a helicopter logged area. The information presented can be used to evaluate the utilization potential of residues, fuel loadings, and the effects of changes in market conditions and contract requirements such as yarding of unutilized material (YUM).[1/]

The character and volume of residues left in a balloon logged area were reported in a previous paper (Pong and Henley 1976). A similar report on the skyline logged area is planned. Other published reports from this study effort deal with yarding rates and costs (Dykstra 1974, 1975, 1976a, 1976b, 1976c).

SCOPE AND PROCEDURE

Residues were inventoried on three 10- to 15-acre units of the helicopter logged sale. The study area was in steep and broken terrain with slopes varying from 10 to 90 percent. Old-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) were the principal species in the study area (about 83 percent by volume). Secondary species included western redcedar (*Thuja plicata* Donn) and true firs (*Abies* spp.).

Cruise volumes and the logging specifications of the units are given in table 1. The timber on units 2 and 3 was similar in that the gross cruise volumes were about 120,000 to 135,000 board feet per acre with an estimated defect of less than 10 percent. The timber on unit 1 contained less volume, about 75,000 board feet per acre, and had significantly more defect, about 38 percent. Units 1 and 2 were clearcut, and unit 3 was partial cut (86-percent volume removal).

[1/] In this report the acronym "YUM" will be used interchangeably to represent both the yarding process and the unutilized material that is yarded.

Table 1--*Cruised data and logging specifications for three study units Pansy Creek helicopter logging sale - Mt. Hood National Forest*

Study unit	Size (acres)	Cruised volumes[1]				Percent defect	Cutting method	YUM[2] specifications
		Gross	Net	Gross per acre	Net per acre			
1	10	749	463	75	46	38.2	clear-cut	12-inch d.i.b.[3] or larger on large end, 10 feet long or longer
2	15	2,050	1,852	137	123	9.7	clear-cut	20-inch d.i.b. or larger on large end, 10 feet long or longer
3	13	1,532	1,429	118	110	6.7	partial-cut[4]	20-inch d.i.b. or larger on large end, 10 feet long or longer

[1] Thousand board feet Scribner.

[2] Yarding of unutilized material.

[3] Diameter inside bark.

[4] Approximately 86 percent of merchantable volume removed.

Specifications in the timber sale contract required that all logs one-third sound with a minimum net scale of 80 board feet be removed. These specifications were applicable to 6-inch-d.i.b. (diameter inside bark) and larger logs at the small end, and to logs at least 8 feet long. The contract also required yarding of unutilized materials (YUM) as shown in table 1.

A planar intersect technique was used to inventory the downed woody residues on the units. The intersect technique involves tallying woody pieces that intersect imaginary vertical sampling planes dropped through the downed debris (Brown 1974, Van Wagner 1968). A systematic grid-point sampling design, with random orientation of a sampling plane at each point, was used to inventory each unit (Howard et al. 1972). At least 40 sample points were located in each unit. Pieces less than 3 inches in diameter were tallied by diameter classes and sampling plane lengths as follows:

0.25 to 0.99 inch	6 feet
1.0 to 2.99 inches	10 feet

Pieces 3 inches and larger were recorded by their diameters to the nearest inch. A 200-foot sampling plane was used for these larger pieces.

Particles qualifying for tally included downed woody material (twigs, stems, branches, and bolewood) from trees and shrubs. Dead branches attached to boles of standing trees were not tallied. Twigs and branches deposited in and above the litter layer were counted. Cones, bark flakes, needles, leaves, grass, and forbs were not counted. Slabs from shattered trees were recorded.

The size classes were chosen for tallying intersections because they permit precise estimates of volume and they correspond to the standard moisture timelags used in the National Fire-Danger Rating System (Deeming et al. 1972).

As each piece of residue 3 inches and greater in diameter (inside bark) was inventoried, the piece was classified according to its potential for utilization. Pieces less than 4 feet in length were not considered to be utilizable, and were classed as fuel. Pieces so decayed or splintered that they would not hold together if yarded were also classed as fuel. All others were placed in one of the following categories:

1. From a felled tree and bucked on at least one end.
2. From a felled tree and broken on both ends.
3. From prelogging (natural) residues, i.e., from dead and down windthrows, etc., and bucked on at least one end.
4. From prelogging residue and broken on both ends.

Information on species, length, and soundness was obtained for each piece considered to be usable. Length was recorded to the nearest foot. Soundness or percent firmwood (proportion of wood usable for pulp chips) was estimated to the nearest 10 percent at the point of

the sampling plane intersection. Estimates of soundness were based on the proportion of the cross-sectional area that was sound and judged as usable for pulp chips. Material decayed or excessively splintered was considered unusable and classed as fuel. The cross-sectional area at the sampling point was usually not visible. Thus, the soundness was estimated on the basis of surface and end characteristics of the piece and by a limited amount of sounding and chopping with hatchets.

These sampling procedures were used to inventory the natural residues present on the unit prior to any harvesting activities and also the residues that were left when the yarding operations were completed. The logging residues were sampled after the required yarding of unutilized material was complete, but prior to any further treatment of the remaining slash.

RESULTS

Harvesting Increased Total Residue Volume

The gross volume of all residues on the ground increased in all three study units following the harvesting operation (table 2). The largest increase occurred in unit 3 where residue volumes increased 44 percent (from 3,964 cubic feet to 5,715 cubic feet per acre), followed by unit 2 with a 25-percent increase (3,749 cubic feet to 4,678 cubic feet), and unit 1 with a 18-percent increase (from 4,528 cubic feet to 5,355 cubic feet). The volumes of residue before and after the logging operation in various diameter classes on each of the three study units are presented in table 3.

YUM Yarding Reduced Coarse Residues

Not all diameter classes of residues increased in volume after logging. In units 1 and 2, volume increases generally were limited to the fuels, smaller size coarse residues (3-13 inches), and residues in the 31.5-34.4-inch diameter class and slabs; decreases were recorded in all other residue sizes. In unit 3, nearly every diameter class of residue increased in volume following logging. In only one diameter class (19.5-22.4 inches) was there a noticeable decrease.

YUM yarding appeared to be effective in reducing the coarse logging residues in the study units. The gross volume of YUM material removed from unit 1, for example, averaged 2,433 cubic feet per acre. This was comparable to the 5,355 cubic feet per acre of logging residue left on the ground. We can assume that most if not all of the YUM volume was in pieces meeting the 12-inch YUM specifications for unit 1 (table 1). Though comparable figures for the YUM removed from units 2 and 3 are not available, results from unit 1 strongly suggest that YUM yarding did reduce the potential volume of coarse logging residues in the study units.

The fact that in units 1 and 2 there was a decrease in the coarse residue volume for many diameter classes following the logging operation indicates that removal of some of the prelogging residue had taken place

Table 2--*Average gross volumes of usable and unusable residues, piece count of usable residues before and after logging, and gross volumes of YUM[1] and merchantable logs removed from three study units, Pansy Creek helicopter sale - Mt. Hood National Forest*[2]

Study unit	Residue			Usable residue	YUM	YUM plus usable residue	Merchantable log volume removed
	Usable	Unusable	Total				
	- - -Cubic feet per acre- - -			Pieces per acre	- - - - - -Cubic feet per acre- - - - - -		
Unit 1:							
Before logging	1,606	2,922	4,528	61	2,433	5,031	6,387
After logging	2,598	2,757	5,355	816			
Unit 2:							
Before logging	1,873	1,876	3,749	94	[3]2,941	6,081	13,477
After logging	3,140	1,538	4,678	1,020			
Unit 3:							
Before logging	1,714	2,250	3,964	129	[3]3,667	7,583	9,598
After logging	3,916	1,799	5,715	1,226			

[1] Yarding of unutilized material (removed during logging operation).

[2] Information in this table is summarized from data presented in other tables in this report.

[3] Estimated from proportions in unit 1.

Table 3--*Average gross volume of residues before and after logging, by diameter class for three study units, Pansy Creek helicopter logging sale - Mt. Hood National Forest*

Diameter class (inches)	Unit 1		Unit 2		Unit 3	
	Before logging[1/]	After logging[2/]	Before logging[1/]	After logging[2/]	Before logging[1/]	After logging[2/]
	- - - - - - - - - - - - - - - - - - Cubic feet per acre - - - - - - - - - - - - - - - - - -					
0.26- 1.0	141.9	133.8	94.6	159.9	165.8	171.2
1.1 - 2.9	205.4	334.1	179.1	479.3	215.9	568.8
3.0 - 4.4	93.4	309.2	46.0	325.7	143.8	251.3
4.5 - 7.4	73.2	342.9	50.9	581.7	206.5	598.1
7.5 - 10.4	233.6	291.2	263.7	585.8	735.3	982.6
10.5 - 13.4	347.2	343.4	442.3	521.0	618.0	901.0
13.5 - 16.4	316.6	288.3	552.0	517.0	750.7	729.4
16.5 - 19.4	309.0	267.1	377.9	316.3	551.0	572.1
19.5 - 22.4	308.4	257.7	455.7	323.9	507.7	196.3
22.5 - 25.4	325.9	249.0	268.7	262.3	26.9	186.1
25.5 - 28.4	290.7	257.3	382.2	131.1	0	214.3
28.5 - 31.4	440.8	361.1	335.9	39.2	42.0	44.8
31.5 - 34.4	47.8	143.8	0	53.9	0	50.8
34.5+	1,387.7	565.6	298.6	57.1	0	0
Slabs	6.8	1,210.9	1.4	323.8	0	248.3
Total	4,528.3	5,355.4	3,748.8	4,678.1	3,963.6	5,715.0

[1/] Dead and down material which includes material not yardable, less than 10 percent sound, and less than 3 inches in diameter and 4 feet long.

[2/] All down material which includes material not yardable, less than 10 percent sound, and less than 3 inches in diameter and 4 feet long.

during the harvesting operation. YUM yarding probably accounted for much of this reduction. Some reduction may also have resulted from the utilization of the sounder pieces of prelogging residue; this was especially true in the larger diameter material.

Even with YUM yarding, residue volumes remaining on unit 3 for most diameter classes were greater than those recorded during the prelogging inventory (table 3). This suggests that YUM yarding in unit 3 (a partial cut) was less effective in reducing coarse residues than in units 1 and 2 (clearcuts).

The gross volume of merchantable logs removed from unit 1 during the helicopter logging operation, as tallied at the truck scale station, was 6,387 cubic feet per acre. This was comparable to the gross residue volume left on the ground of 5,355 cubic feet and a total unused wood volume (logging residue plus YUM) of 7,788 cubic feet. Comparable figures for units 2 and 3 were not recorded.

Utilization Potential of Residues

The portion of the total residue volume that has some potential for utilization is defined as material which can be yarded without breaking up and is at least 10 percent sound, 3 inches and greater in diameter, and at least 4 feet long. According to these specifications, on unit 1, 1,606 cubic feet per acre--about 35 percent of the prelogging residue (coefficient of variation of 90.2 percent), on unit 2, 1,873 cubic feet per acre--about 50 percent (coefficient of variation of 91.0 percent), and on unit 3, 1,714 cubic feet per acre--about 43 percent (coefficient of variation of 67.8 percent) could be utilized. A breakdown of these volumes by diameter and length classes for each unit are contained in tables 4, 5, and 6. Some of the larger and sounder natural residues were probably salvaged during the harvesting operation; the remainder was either removed as YUM or left on the site. Volumes of usable and unusable prelogging residues for each unit are graphically presented in figure 1 and summarized in table 2.

Much of the prelogging residue was defective. The average soundness of the usable prelogging residues was 63 percent for unit 1, 72 percent for unit 2, and 65 percent for unit 3. Comparable figures for the logging residues were higher, averaging 65 percent for unit 1 and 81 percent for units 2 and 3. Removal of the larger and sounder prelogging residues during the logging operation reduced, to some extent, the average soundness of the remaining residues. The yarding of the unutilized material, however, tends to increase the average soundness of the residue left on the logging site. This is especially true if some of the material removed as YUM did not have the potential for utilization according to our study specifications. A decrease in unusable residue volume on each of the study units (table 2) after logging and YUM yarding indicates that some removal of this type material had occurred. The species composition and soundness data of the usable residues before and after the harvesting operation on each study unit are presented in tables 7-12.

Table 4--*Average gross and net volumes of usable prelogging residue by diameter and length classes, Study Unit 1, Pansy Creek helicopter logging sale*[1]*/-Mt. Hood National Forest*

Diameter class (inches)	Volume of all classes		Length class (feet)							
			4.0-7.9		8.0-13.9		14.0-20.9		21.0+	
	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net
	-Cubic feet per acre-									
3.0 - 4.4	12.4	10.4	5.2	4.6	4.2	3.6	1.7	1.2	1.3	1.0
4.5 - 7.4	11.2	9.1	2.9	1.3	4.5	4.1	2.6	2.6	1.2	1.2
7.5 - 10.4	41.4	35.7	2.3	.5	9.8	9.0	8.3	8.2	21.0	18.1
10.5 - 13.4	53.7	24.5	6.7	3.0	16.8	4.0	3.4	1.3	26.9	16.1
13.5 - 16.4	90.3	53.1	0	0	31.6	17.0	9.1	5.5	49.5	30.6
16.5 - 19.4	67.2	46.9	0	0	22.7	18.1	0	0	44.5	28.7
19.5 - 22.4	76.6	38.4	9.3	1.9	0	0	9.3	2.8	57.9	33.8
22.5 - 25.4	218.4	122.4	14.6	0	26.9	6.7	26.9	9.4	150.1	106.3
25.5 - 28.4	227.6	132.8	0	0	18.3	11.0	65.6	27.7	143.8	94.1
28.5 - 31.4	188.9	128.1	0	0	0	0	21.0	12.6	167.9	115.5
31.5 - 34.4	47.8	26.3	0	0	0	0	23.9	4.8	23.9	21.5
34.5+	563.3	383.2	0	0	0	0	0	0	563.3	383.2
Slabs	6.8	4.6	1.1	1.1	2.1	2.1	3.6	1.4	0	0
Total	1,605.7	1,015.5	42.1	12.4	137.0	75.7	175.3	77.5	1,251.3	850.0

[1] Includes all dead and down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, at least 10 percent sound, and yardable.

Table 5--*Average gross and net volumes of usable prelogging residue by diameter and length classes, Study Unit 2, Pansy Creek helicopter logging sale*[1/]*- Mt. Hood National Forest*

Diameter class (inches)	Volume of all classes		Length class (feet)							
			4.0-7.9		8.0-13.9		14.0-20.9		21.0+	
	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net
	- - -

Table 6--*Average gross and net volumes of usable prelogging residue by diameter and length classes, Study Unit 3, Pansy Creek helicopter logging sale*[1]*- Mt. Hood National Forest*

Diameter class (inches)	Volume of all classes		Length class (feet)							
			4.0-7.9		8.0-13.9		14.0-20.9		21.0+	
	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net
	Cubic feet per acre									
3.0 - 4.4	4.8	2.9	0	0	1.2	.3	1.3	.9	2.3	1.7
4.5 - 7.4	39.0	30.3	5.7	3.2	1.2	.2	14.7	12.7	17.4	14.2
7.5 - 10.4	305.2	210.6	31.0	20.3	49.7	32.0	73.4	50.8	151.1	107.5
10.5 - 13.4	268.7	165.9	26.9	17.5	53.7	24.2	67.2	39.6	120.9	84.6
13.5 - 16.4	441.5	231.5	45.7	9.6	66.8	34.4	84.3	45.8	244.6	141.8
16.5 - 19.4	302.3	192.0	0	0	45.3	10.6	45.3	22.7	211.6	158.7
19.5 - 22.4	283.8	221.8	0	0	56.0	37.3	37.3	31.7	190.5	152.8
22.5 - 25.4	26.9	24.2	0	0	0	0	0	0	26.9	24.2
25.5 - 28.4	0	0	0	0	0	0	0	0	0	0
28.5 - 31.4	42.0	33.6	0	0	0	0	0	0	42.0	33.6
31.5 - 34.4	0	0	0	0	0	0	0	0	0	0
34.5+	0	0	0	0	0	0	0	0	0	0
Slabs	0	0	0	0	0	0	0	0	0	0
Total	1,714.0	1,112.8	109.3	50.5	273.9	139.0	323.6	204.1	1,007.3	719.1

[1] Includes all dead and down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, at least 10 percent sound, and yardable.

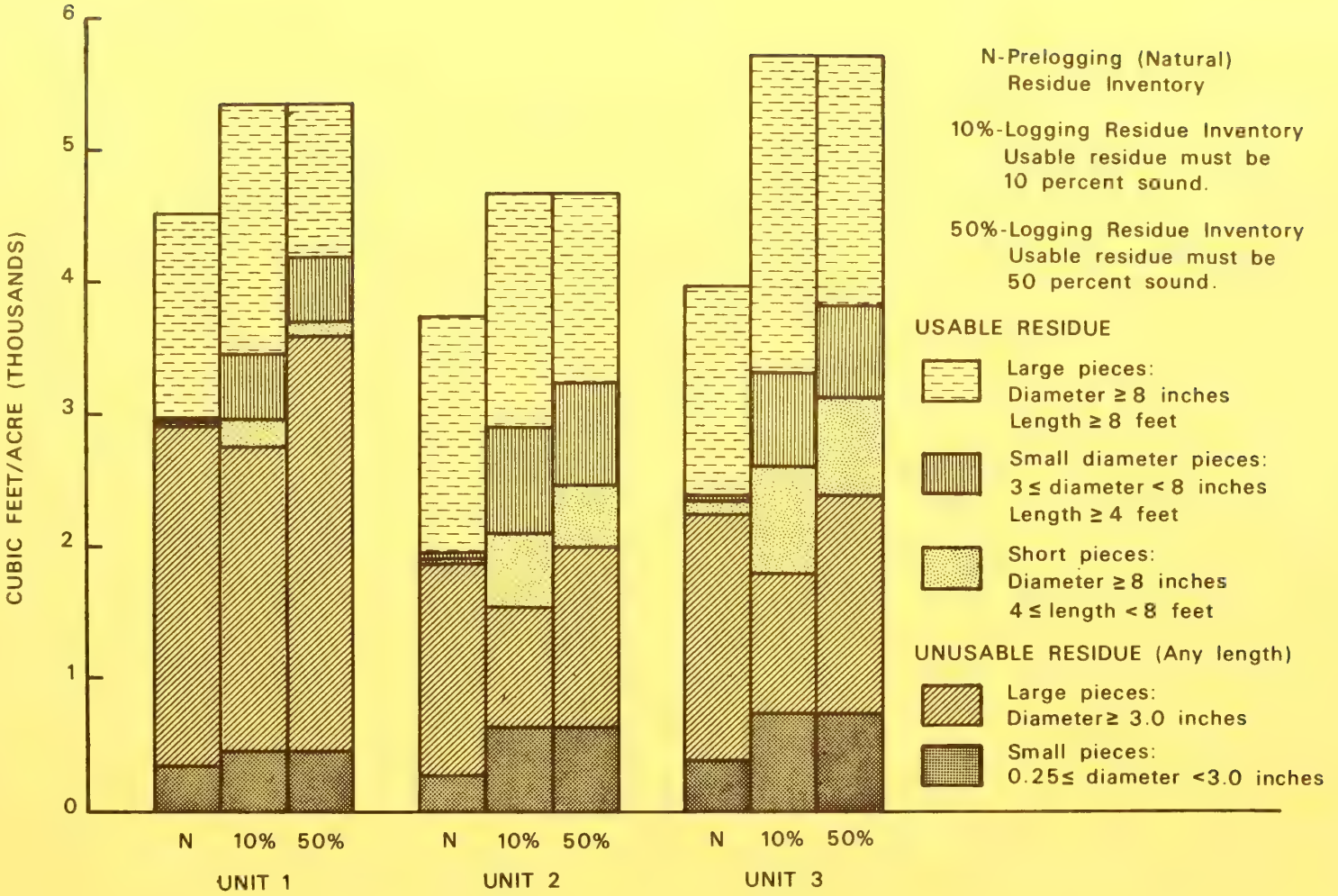

Figure 1.--Average gross volume of usable and unusable prelogging and logging residues grouped by soundness and size for three helicopter study units--Pansy Creek helicopter logging sale, Mt. Hood National Forest.

Table 7--*Average gross and net volumes of usable prelogging residue by species, Study Unit* 1, *Pansy Creek helicopter logging sale*[1/] *- Mt. Hood National Forest*

Species	Gross volume	Net volume	Soundness	Proportion of total
	- - -Cubic feet per acre- - -		- - -Percent- - -	
Douglas-fir	38.8	26.9	69.3	2.4
Hemlock	1,041.5	592.9	56.9	64.9
Cedar	459.8	331.9	72.2	28.6
Pines	13.4	13.4	100.0	.8
Other softwoods	52.0	50.3	96.8	3.2
Hardwoods	0	0	0	0
Total	1,605.7	1,015.5	63.2	[2/]99.9

[1/] Includes all dead and down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, at least 10 percent sound, and yardable.

[2/] Total does not equal 100 because of rounding.

Table 8--*Average gross and net volumes of usable prelogging residue by species, Study Unit 2, Pansy Creek helicopter logging sale*[1]*-Mt. Hood National Forest*

Species	Gross volume	Net volume	Soundness	Proportion of total
	- - -Cubic feet per acre- - -		- - -Percent- - -	
Douglas-fir	1,291.7	852.1	66.0	69.0
Hemlock	238.0	162.5	68.3	12.7
Cedar	0	0	0	0
Pines	333.8	321.3	96.2	17.8
Other softwoods	9.1	9.1	100.0	.5
Hardwoods	0	0	0	0
Total	1,872.6	1,345.0	71.8	100.0

[1] Includes all dead and down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, at least 10 percent sound, and yardable.

Table 9--*Average gross and net volumes of usable prelogging residue by species, Study Unit 3, Pansy Creek helicopter logging sale*[1]*-Mt. Hood National Forest*

Species	Gross volume	Net volume	Soundness	Proportion of total
	- - -Cubic feet per acre- - -		- - -Percent- - -	
Douglas-fir	1,564.8	1,026.1	65.6	91.3
Hemlock	44.7	41.5	92.8	2.6
Cedar	0	0	0	0
Pines	0	0	0	0
Other softwoods	104.5	45.2	43.2	6.1
Hardwoods	0	0	0	0
Total	1,714.0	1,112.8	64.9	100.0

[1] Includes all dead and down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, at least 10 percent sound, and yardable.

Table 10--*Average gross and net volumes of usable logging residue by soundness and species, Study Unit* 1, *Pansy Creek helicopter logging sale*[1/]*--Mt. Hood National Forest*

Percent soundness and species	Gross volume	Net volume	Soundness	Proportion of total
	- - -Cubic feet per acre- - -		- - -Percent- - -	
75+ percent sound:				
Douglas-fir	198.9	192.5	96.8	16.6
Hemlock	497.5	491.2	98.7	41.6
Cedar	0	0	0	0
Pines	0	0	0	0
Other softwoods	498.3	485.7	97.5	41.7
Hardwoods	.8	.8	100.0	.1
Total	1,195.5	1,170.2	97.9	100.0
50+ percent sound:				
Douglas-fir	282.6	243.4	86.1	16.0
Hemlock	740.4	626.8	84.7	42.0
Cedar	0	0	0	0
Pines	0	0	0	0
Other softwoods	740.0	632.3	85.4	42.0
Hardwoods	.8	.8	100.0	0
Total	1,763.8	1,503.3	85.2	100.0
30+ percent sound:				
Douglas-fir	343.6	262.1	76.3	16.3
Hemlock	826.6	658.6	79.7	39.1
Cedar	0	0	0	0
Pines	0	0	0	0
Other softwoods	940.9	705.5	75.0	44.6
Hardwoods	.8	.8	100.0	0
Total	2,111.9	1,626.9	77.0	100.0
10+ percent sound:				
Douglas-fir	418.2	276.6	66.1	16.1
Hemlock	924.7	672.9	72.8	35.6
Cedar	0	0	0	0
Pines	0	0	0	0
Other softwoods	1,254.6	744.0	59.3	48.3
Hardwoods	.8	.8	100.0	0
Total	2,598.3	1,694.3	65.2	100.0

[1/] Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

Table 11--*Average gross and net volumes of usable logging residue by soundness and species, Study Unit 2, Pansy Creek helicopter logging sale*[1]*--Mt. Hood National Forest*

Percent soundness and species	Gross volume	Net volume	Soundness	Proportion of total
	- - -Cubic feet per acre- - -		- - -Percent- - -	
75+ percent sound:				
Douglas-fir	776.8	724.2	93.2	34.1
Hemlock	274.5	271.9	99.0	12.1
Cedar	0	0	0	0
Pines	12.2	12.2	100.0	.5
Other softwoods	1,213.3	1,186.5	97.8	53.3
Hardwoods	1.3	1.3	100.0	.1
Total	2,278.1	2,196.1	96.4	[2]100.1
50+ percent sound:				
Douglas-fir	1,037.2	887.0	85.5	38.5
Hemlock	293.4	281.4	95.9	10.9
Cedar	0	0	0	0
Pines	12.2	12.2	100.0	.5
Other softwoods	1,346.6	1,266.4	94.0	50.0
Hardwoods	1.3	1.3	100.0	0
Total	2,690.6	2,448.2	91.0	[2]99.9
30+ percent sound:				
Douglas-fir	1,144.6	923.0	80.6	39.4
Hemlock	293.4	281.4	95.9	10.1
Cedar	0	0	0	0
Pines	12.2	12.2	100.0	.4
Other softwoods	1,451.4	1,300.3	89.6	50.0
Hardwoods	1.3	1.3	100.0	0
Total	2,903.0	2,518.1	86.7	[2]99.9
10+ percent sound:				
Douglas-fir	1,204.8	930.4	77.2	38.4
Hemlock	296.4	281.4	94.9	9.4
Cedar	0	0	0	0
Pines	12.2	12.2	100.0	.4
Other softwoods	1,624.8	1,321.1	81.3	51.8
Hardwoods	1.3	1.3	100.0	0
Total	3,139.5	2,546.3	81.1	100.0

[1] Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

[2] Total does not equal 100 because of rounding.

Table 12--*Average gross and net volumes of usable logging residue by soundness and species, Study Unit 3, Pansy Creek helicopter logging sale*[1]*--Mt. Hood National Forest*

Percent soundness and species	Gross volume	Net volume	Soundness	Proportion of total
	- - -Cubic feet per acre- - -		- - -Percent- - -	
75+ percent sound:				
Douglas-fir	1,398.7	1,364.6	97.6	50.5
Hemlock	748.0	744.8	99.6	27.0
Cedar	0	0	0	0
Pines	0	0	0	0
Other softwoods	620.7	587.0	94.6	22.4
Hardwoods	0	0	0	0
Total	2,767.4	2,696.4	97.4	[2]99.9
50+ percent sound:				
Douglas-fir	1,773.3	1,579.0	89.0	53.4
Hemlock	819.7	786.0	95.9	24.7
Cedar	0	0	0	0
Pines	0	0	0	0
Other softwoods	724.7	648.1	89.4	21.8
Hardwoods	0	0	0	0
Total	3,317.6	3,013.2	90.8	[2]99.9
30+ percent sound:				
Douglas-fir	1,961.5	1,648.9	84.1	54.5
Hemlock	856.4	800.7	93.5	23.8
Cedar	0	0	0	0
Pines	0	0	0	0
Other softwoods	778.7	666.4	85.6	21.7
Hardwoods	0	0	0	0
Total	3,596.7	3,116.0	86.6	100.0
10+ percent sound:				
Douglas-fir	2,139.2	1,676.7	78.4	54.6
Hemlock	862.4	801.6	92.9	22.0
Cedar	0	0	0	0
Pines	0	0	0	0
Other softwoods	914.4	682.7	74.7	23.3
Hardwoods	0	0	0	0
Total	3,916.0	3,161.0	80.7	[2]99.9

[1] Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

[2] Total does not equal 100 because of rounding.

About 49 percent, or 2,598 cubic feet per acre (coefficient of variation of 65.8 percent), of the residue remaining after harvesting on unit 1 had utilization potential according to the study specifications. For unit 2, 67 percent, or 3,140 cubic feet per acre (coefficient of variation of 41.1 percent), met these specifications. On unit 3, 69 percent, or 3,916 cubic feet per acre (coefficient of variation of 40.8 percent), could have been used. The average gross and net volumes of usable logging residue remaining on the site are shown for each unit by soundness and by diameter and length classes in tables 13-15. Volumes of usable and unusable logging residue by two soundness classes (10 and 50 percent) are presented in figure 1. A summary of residue volumes for each unit is presented in table 2.

The utilization potential of the residues (both natural and logging) was reduced considerably as the direct result of the harvesting activities. Many pieces were broken and shattered when trees were felled and yarded. The large increase in slab volume after logging in the three units (table 3) indicates considerable shattering occurred during the harvesting operations. Yarding of YUM also contributed to the increase in slab volume. In unit 1 nearly 23 percent of the logging residue volume was in the form of slabs. In units 2 and 3 slabs accounted for 7 and 4 percent, respectively. The highly defective condition of the timber in unit 1 (table 1) probably contributed heavily to the generation of slabs in that unit. Only 1 to 3 percent of the slabs on the study units were considered usable.

We can assume that most of the YUM either met or exceeded the minimum specifications for utilization. For unit 1 the gross volume of YUM was 2,433 cubic feet per acre. When combined with the gross volume of usable residue left on the ground (2,598 cubic feet per acre, see table 13), a total of 5,031 cubic feet per acre of potentially usable residue results (table 2). This is comparable to 6,387 cubic feet per acre of merchantable logs removed from unit 1 during the helicopter logging operation and represents nearly 65 percent of the total residue volume (7,788 cubic feet per acre) generated on the unit (5,355 cubic feet per acre left on the ground, see table 3, plus 2,433 cubic feet per acre of YUM, see table 2).

Though the volumes of YUM removed from units 2 and 3 were not recorded, results from unit 1 suggest that a large part of the usable residues generated on each of the study units was removed as YUM. If this is the case, the recorded usable residues remaining on units 2 and 3 (3,140 and 3,916 cubic feet per acre, respectively, see tables 14 and 15) represent only a portion of the total usable residues available from each of the study units. For unit 1, about 48 percent of the total usable residues was removed as YUM. If we assume that the potential volume of YUM from unit 2 and 3 would be in the same proportions as that removed from unit 1, then the YUM from unit 2 would be 2,941 cubic feet per acre and from unit 3, 3,667 cubic feet per acre. When these amounts are combined with the appropriate volumes of usable residue left on each site, the total usable residues generated would be 6,081 cubic feet per acre on unit 2 and 7,583 cubic feet per acre on unit 3 (table 2). These volumes represent approximately 80 percent of all residues generated on each site, i.e., the residue volume remaining on the ground (table 3) plus the calculated YUM.

Table 13--Average gross and net volumes of usable logging residue by soundness and by diameter and length classes, Study Unit 1, Pansy Creek helicopter logging sale[1]--Mt. Hood National Forest

Percent soundness and diameter class (inches)	Volume of all classes		Length class (feet)							
			4.0-7.9		8.0-13.9		14.0-20.9		21.0+	
	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net
	Cubic feet per acre									
75+ percent sound:										
3.0 - 4.4	202.3	200.0	118.0	116.2	56.3	55.8	19.2	19.2	8.8	8.8
4.5 - 7.4	257.1	254.6	68.8	67.8	63.1	62.1	51.3	51.2	73.9	73.6
7.5 - 10.4	205.2	203.0	26.2	25.3	37.4	37.1	48.7	48.1	92.9	92.5
10.5 - 13.4	194.7	191.3	21.4	20.2	37.3	36.4	51.8	51.6	84.2	83.2
13.5 - 16.4	97.3	92.9	0	0	42.0	39.5	28.6	27.5	26.7	25.9
16.5 - 19.4	49.6	47.8	12.9	12.3	5.4	5.4	12.2	11.0	19.0	19.0
19.5 - 22.4	24.2	21.2	7.5	6.0	16.7	15.2	0	0	0	0
22.5 - 25.4	21.7	21.7	0	0	0	0	10.9	10.9	10.9	10.9
25.5 - 28.4	79.5	76.9	14.8	14.8	25.5	25.5	13.7	13.7	25.5	22.9
28.5 - 31.4	31.7	28.5	15.9	14.3	0	0	0	0	15.9	14.3
31.5 - 34.4	0	0	0	0	0	0	0	0	0	0
34.5+	31.7	31.7	0	0	0	0	0	0	31.7	31.7
Slabs	.6	.6	.2	.2	.4	.4	0	0	0	0
Total	1,195.5	1,170.2	285.8	277.1	284.0	277.3	236.4	233.2	389.3	382.7
50+ percent sound:										
3.0 - 4.4	214.5	207.1	128.8	122.5	57.4	56.5	19.5	19.4	8.8	8.8
4.5 - 7.4	273.0	264.4	75.5	71.9	68.3	65.4	54.7	53.3	74.4	73.9
7.5 - 10.4	213.5	208.7	29.3	27.4	41.0	39.6	50.2	49.2	92.9	92.5
10.5 - 13.4	217.4	204.3	24.6	21.8	37.3	36.4	51.8	51.6	103.7	94.6
13.5 - 16.4	127.5	111.8	0	0	54.7	48.4	33.5	29.9	39.4	33.5
16.5 - 19.4	66.6	58.0	12.9	12.3	10.9	8.7	12.2	11.0	30.6	26.0
19.5 - 22.4	96.0	65.7	15.1	11.3	40.8	30.6	25.0	14.8	15.1	9.0
22.5 - 25.4	52.5	40.2	0	0	10.0	6.0	10.9	10.9	31.7	23.4
25.5 - 28.4	93.2	85.2	14.8	14.8	25.5	25.5	13.7	13.7	39.2	31.2
28.5 - 31.4	163.0	104.1	15.9	14.3	15.9	7.9	48.7	27.6	82.6	54.3
31.5 - 34.4	21.8	13.1	0	0	0	0	0	0	21.8	13.1
34.5+	224.4	140.0	0	0	0	0	27.2	16.3	197.1	123.7
Slabs	.6	.6	.2	.2	.4	.4	0	0	0	0
Total	1,763.8	1,503.3	317.0	296.4	362.1	325.3	347.4	297.7	737.2	584.0
30+ percent sound:										
3.0 - 4.4	216.1	207.7	130.0	122.9	57.8	56.7	19.5	19.4	8.8	8.8
4.5 - 7.4	281.2	267.1	79.6	73.3	71.5	66.4	55.7	53.6	74.4	73.9
7.5 - 10.4	222.4	212.0	32.4	28.6	46.8	41.7	50.2	49.2	92.9	92.5
10.5 - 13.4	240.1	211.9	32.3	24.3	46.4	39.7	51.8	51.6	109.6	96.4
13.5 - 16.4	149.4	119.6	8.5	2.9	63.2	51.4	33.5	29.9	44.2	35.5
16.5 - 19.4	96.5	67.6	31.9	18.6	10.9	8.7	17.7	12.6	36.0	27.7
19.5 - 22.4	111.0	71.0	15.1	11.3	48.4	33.6	25.0	14.8	22.6	11.3
22.5 - 25.4	128.6	68.4	0	0	20.8	9.2	10.9	10.9	96.9	48.3
25.5 - 28.4	106.0	90.3	14.8	14.8	25.5	25.5	13.7	13.7	52.0	36.3
28.5 - 31.4	178.9	108.9	15.9	14.3	15.9	7.9	48.7	27.6	98.5	59.1
31.5 - 34.4	21.8	13.1	0	0	0	0	0	0	21.8	13.1
34.5+	358.1	188.2	0	0	0	0	50.3	25.6	307.8	162.7
Slabs	1.9	1.1	.2	.2	1.7	.9	0	0	0	0
Total	2,111.9	1,626.9	360.7	311.2	408.9	341.6	376.9	308.8	965.4	665.3
10+ percent sound:										
3.0 - 4.4	218.8	208.2	131.9	123.2	58.3	56.8	19.8	19.4	8.8	8.8
4.5 - 7.4	289.9	268.1	82.6	73.6	74.5	66.8	58.0	53.8	74.9	73.9
7.5 - 10.4	242.0	214.6	37.0	29.2	55.4	42.8	50.2	49.2	99.4	93.4
10.5 - 13.4	266.5	214.8	41.4	25.5	48.7	39.9	58.6	52.3	117.7	97.2
13.5 - 16.4	201.0	126.1	22.4	4.8	70.6	52.1	55.9	32.5	52.1	36.7
16.5 - 19.4	163.8	76.1	38.7	19.3	21.8	10.3	43.5	15.2	59.8	31.3
19.5 - 22.4	177.6	80.2	15.1	11.3	57.5	35.4	40.1	17.1	65.0	16.4
22.5 - 25.4	150.3	71.6	10.9	1.1	20.8	9.2	10.9	10.9	107.8	50.4
25.5 - 28.4	162.0	101.5	14.8	14.8	25.5	25.5	13.7	13.7	108.0	47.5
28.5 - 31.4	246.7	113.9	15.9	14.3	31.7	9.5	48.7	27.6	150.5	62.5
31.5 - 34.4	42.3	17.2	0	0	0	0	0	0	42.3	17.2
34.5+	428.8	199.7	0	0	0	0	77.5	28.3	351.3	171.4
Slabs	8.5	2.4	6.8	1.5	1.7	.9	0	0	0	0
Total	2,598.3	1,694.3	417.4	318.5	466.5	349.3	476.8	320.0	1,237.6	706.6

[1] Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

Table 14--Average gross and net volumes of usable logging residue by soundness and by diameter and length classes, Study Unit 2, Pansy Creek helicopter logging sale[1]--Mt. Hood National Forest

Percent soundness and diameter class (inches)	Volume of all classes		Length class (feet)							
			4.0-7.9		8.0-13.9		14.0-20.9		21.0+	
	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net
	-Cubic feet per acre-									
75+ percent sound:										
3.0 - 4.4	241.6	239.5	126.3	124.6	60.1	59.9	28.4	28.2	26.9	26.8
4.5 - 7.4	514.4	505.9	80.6	77.9	125.6	123.1	130.9	129.1	177.3	175.8
7.5 - 10.4	449.4	443.9	100.7	99.1	86.0	85.4	70.7	69.5	192.1	189.9
10.5 - 13.4	309.6	299.4	47.3	46.7	87.8	87.1	37.2	36.6	137.3	128.9
13.5 - 16.4	186.0	175.1	45.7	45.7	49.8	44.0	48.4	46.6	42.1	38.8
16.5 - 19.4	180.0	170.6	30.3	30.3	45.4	42.4	72.3	69.3	32.0	28.6
19.5 - 22.4	140.4	132.5	78.6	74.8	18.7	18.7	22.6	22.6	20.6	16.5
22.5 - 25.4	105.4	100.0	29.2	29.2	0	0	49.4	49.4	26.9	21.5
25.5 - 28.4	34.0	34.0	0	0	34.0	34.0	0	0	0	0
28.5 - 31.4	0	0	0	0	0	0	0	0	0	0
31.5 - 34.4	53.9	43.1	0	0	0	0	53.9	43.1	0	0
34.5+	57.1	45.7	57.1	45.7	0	0	0	0	0	0
Slabs	6.2	6.2	6.2	6.2	0	0	0	0	0	0
Total	2,278.1	2,196.1	602.0	580.3	507.3	494.6	513.7	494.4	655.0	626.7
50+ percent sound:										
3.0 - 4.4	242.9	240.4	127.1	125.2	60.5	60.1	28.4	28.2	26.9	26.8
4.5 - 7.4	522.9	511.3	85.2	80.5	125.6	123.1	134.9	131.9	177.3	175.8
7.5 - 10.4	472.3	456.7	105.4	101.9	92.7	88.8	75.3	72.3	198.8	193.7
10.5 - 13.4	381.5	340.6	58.6	53.5	109.2	99.4	50.6	44.7	163.1	143.0
13.5 - 16.4	310.8	254.0	66.7	59.4	81.4	60.9	57.6	53.0	105.1	80.8
16.5 - 19.4	228.8	200.1	30.3	30.3	60.6	50.0	72.3	69.3	65.6	50.5
19.5 - 22.4	220.8	180.8	97.2	87.9	18.7	18.7	22.6	22.6	82.4	51.7
22.5 - 25.4	159.2	135.2	58.3	49.6	0	0	49.4	49.4	51.5	36.3
25.5 - 28.4	34.0	34.0	0	0	34.0	34.0	0	0	0	0
28.5 - 31.4	0	0	0	0	0	0	0	0	0	0
31.5 - 34.4	53.9	43.1	0	0	0	0	53.9	43.1	0	0
34.5+	57.1	45.7	57.1	45.7	0	0	0	0	0	0
Slabs	6.2	6.2	6.2	6.2	0	0	0	0	0	0
Total	2,690.6	2,448.2	692.2	640.3	582.6	534.9	545.0	514.5	870.8	758.6
30+ percent sound:										
3.0 - 4.4	244.5	240.9	128.0	125.4	61.3	60.4	28.4	28.2	26.9	26.8
4.5 - 7.4	538.3	516.5	90.8	82.4	131.8	125.4	136.1	132.2	179.6	176.5
7.5 - 10.4	475.3	457.9	105.4	101.9	95.7	90.0	75.3	72.3	198.8	193.7
10.5 - 13.4	416.4	353.2	64.2	55.2	117.1	102.6	50.6	44.7	184.5	150.8
13.5 - 16.4	341.0	264.0	66.7	59.4	102.4	68.1	57.6	53.0	114.3	83.6
16.5 - 19.4	228.8	200.1	30.3	30.3	60.6	50.0	72.3	69.3	65.6	50.5
19.5 - 22.4	243.4	189.8	119.8	96.9	18.7	18.7	22.6	22.6	82.4	51.7
22.5 - 25.4	159.2	135.2	58.3	49.6	0	0	49.4	49.4	51.5	36.3
25.5 - 28.4	99.5	53.7	0	0	34.0	34.0	0	0	65.5	19.7
28.5 - 31.4	39.2	11.8	0	0	0	0	0	0	39.2	11.8
31.5 - 34.4	53.9	43.1	0	0	0	0	53.9	43.1	0	0
34.5+	57.1	45.7	57.1	45.7	0	0	0	0	0	0
Slabs	6.2	6.2	6.2	6.2	0	0	0	0	0	0
Total	2,903.0	2,518.1	726.9	653.1	621.6	549.0	546.1	514.8	1,008.4	801.2
10+ percent sound:										
3.0 - 4.4	247.9	241.2	129.1	125.6	63.5	60.6	28.4	28.2	26.9	26.8
4.5 - 7.4	550.2	518.3	93.1	82.6	131.8	125.4	141.7	133.0	183.5	177.2
7.5 - 10.4	510.0	463.0	117.6	103.5	104.7	91.7	85.1	73.7	202.6	194.0
10.5 - 13.4	435.6	355.9	64.2	55.2	125.0	104.1	56.3	45.2	190.1	151.3
13.5 - 16.4	432.9	276.1	66.7	59.4	161.4	76.9	80.0	56.3	124.8	83.6
16.5 - 19.4	242.3	200.1	30.3	30.3	60.6	50.0	85.8	69.3	65.6	50.5
19.5 - 22.4	280.7	193.6	138.5	98.8	18.7	18.7	22.6	22.6	101.0	53.5
22.5 - 25.4	183.9	137.7	83.0	52.0	0	0	49.4	49.4	51.5	36.3
25.5 - 28.4	99.5	53.7	0	0	34.0	34.0	0	0	65.5	19.7
28.5 - 31.4	39.2	11.8	0	0	0	0	0	0	39.2	11.8
31.5 - 34.4	53.9	43.1	0	0	0	0	53.9	43.1	0	0
34.5+	57.1	45.7	57.1	45.7	0	0	0	0	0	0
Slabs	6.2	6.2	6.2	6.2	0	0	0	0	0	0
Total	3,139.5	2,546.3	785.9	659.4	699.6	561.4	603.1	520.8	1,050.9	840.8

[1] Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

Table 15--Average gross and net volumes of usable logging residue by soundness and by diameter and length classes, Study Unit 3, Pansy Creek helicopter logging sale[1/]--Mt. Hood National Forest

Percent soundness and diameter class inches	Volume of all classes		Length class (feet)							
			4.0-7.9		8.0-13.9		14.0-20.9		21.0+	
	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net
	- - -

The piece count of usable residues per acre (excluding YUM) increased nearly tenfold or more after harvesting. Unit 1 had the largest increase with a piece count 13 times greater per acre than that recorded prior to logging. Most of the increase occurred in the small diameter classes of residue. The number of pieces of usable residue per acre is summarized by soundness and by diameter and length classes for each unit before (tables 16-18) and after (table 19-21) the logging operation.

Specifications for yarding unutilized material (see table 1) influenced the distribution of usable residue remaining on the three logging units. There was less volume and fewer pieces of usable residue 12 to 19 inches in diameter on unit 1 (tables 13 and 19) than on units 2 and 3 (tables 14-15 and 20-21). Minimum specifications for YUM on unit 1 included residues in this size range; these were excluded as YUM in units 2 and 3. Because YUM yarding removed the larger pieces of unutilized material from the logging sites, the volume of usable residue remaining was predominantly in pieces not meeting YUM specifications.

Logging residues that were at least 50 percent sound, 8 inches and greater in diameter, and at least 8 feet long averaged 1,163 cubic feet per acre on unit 1, 1,445 cubic feet per acre on unit 2, and 1,886 cubic feet per acre on unit 3 (tables 13-15 and figure 1). These volumes comprise 45 to 48 percent of the usable residues on the study units and probably meet or exceed pulp or utility log specifications. Piece counts corresponding to these volumes are 52 per acre on unit 1, 96 on unit 2, and 142 on unit 3 (tables 19-21). These counts represent, respectively, 6, 9, and 12 percent of the usable pieces of residue on an average acre of each unit. Not included in these estimates is the YUM material removed during the logging operation which meets these specifications.

More than 66 percent of the gross volume of usable residue on unit 1 was from felled trees. On unit 2 this class of residue was nearly 75 percent of the gross volume and on unit 3, 74 percent. Of these amounts, about 56 percent was bucked from longer pieces on unit 1, 60 percent on unit 2, and 65 percent on unit 3. For the previously down residue remaining on the logged units, 11 percent had been bucked from longer pieces on unit 1, 25 percent on unit 2, and 26 percent on unit 3. The volumes of usable logging residue on each logging unit by soundness and material handling class are presented in tables 22-24.

For the three units combined, about 50 percent of the usable residue volume was recorded as having been bucked from larger pieces (i.e., felled and bucked plus down and bucked classes, see tables 22-24). With an alternative bucking procedure, some of this material could have been easily removed from the logging sites. Such a procedure would minimize the amount of tree bole residue left on the area by limiting long butting and bucking out of submerchantable or defective segments and broken log ends. This material would then be yarded intact with the merchantable logs or with the YUM material.

Table 16--*Average number of pieces per acre of usable prelogging residue by diameter and length classes, Study Unit 1, Pansy Creek helicopter logging sale*[1/]*-Mt. Hood National Forest*

Diameter class (inches)	Number of pieces all classes	Length class (feet)			
		4.0-7.9	8.0-13.9	14.0-20.9	21.0+
3.0 - 4.4	21.0	13.0	6.0	1.0	1.0
4.5 - 7.4	7.0	3.0	2.0	1.0	0
7.5 - 10.4	6.0	1.0	2.0	1.0	2.0
10.5 - 13.4	5.0	2.0	2.0	0	1.0
13.5 - 16.4	4.0	0	2.0	1.0	2.0
16.5 - 19.4	2.0	0	1.0	0	1.0
19.5 - 22.4	2.0	1.0	0	0	1.0
22.5 - 25.4	4.0	1.0	1.0	1.0	2.0
25.5 - 28.4	3.0	0	0	1.0	1.0
28.5 - 31.4	2.0	0	0	0	1.0
31.5 - 34.4	0	0	0	0	0
34.5+	2.0	0	0	0	2.0
Slabs	1.0	1.0	0	0	0
Total	61.0	21.0	18.0	7.0	15.0

[1/] Includes all dead and down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, at least 10 percent sound, and yardable.

Table 17--*Average number of pieces per acre of usable prelogging residue by diameter and length classes, Study Unit 1, Pansy Creek helicopter logging sale*[1/]*-Mt. Hood National Forest*

Diameter class (inches)	Number of pieces all classes	Length class (feet)			
		4.0-7.9	8.0-13.9	14.0-20.9	21.0+
3.0 - 4.4	16.0	11.0	3.0	1.0	1.0
4.5 - 7.4	17.0	3.0	8.0	2.0	4.0
7.5 - 10.4	24.0	2.0	7.0	6.0	9.0
10.5 - 13.4	11.0	2.0	2.0	2.0	5.0
13.5 - 16.4	8.0	0	1.0	1.0	6.0
16.5 - 19.4	4.0	0	1.0	1.0	2.0
19.5 - 22.4	5.0	2.0	0	1.0	3.0
22.5 - 25.4	1.0	0	0	1.0	0
25.5 - 28.4	4.0	0	2.0	1.0	1.0
28.5 - 31.4	3.0	0	0	0	3.0
31.5 - 34.4	0	0	0	0	0
34.5+	2.0	0	1.0	0	1.0
Slabs	1.0	0	1.0	0	0
Total	94.0	19.0	26.0	13.0	37.0

[1/] Includes all dead and down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, at least 10 percent sound, and yardable.

Table 18--*Average number of pieces per acre of usable prelogging residue by diameter and length classes, Study Unit 3, Pansy Creek helicopter logging sale*[1]*--Mt. Hood National Forest*

Diameter class (inches)	Number of pieces all classes	Length class (feet)			
		4.0-7.9	8.0-13.9	14.0-20.9	21.0+
3.0 - 4.4	5.0	0	2.0	2.0	1.0
4.5 - 7.4	15.0	6.0	1.0	5.0	3.0
7.5 - 10.4	44.0	11.0	11.0	10.0	13.0
10.5 - 13.4	24.0	6.0	7.0	5.0	6.0
13.5 - 16.4	26.0	8.0	6.0	4.0	8.0
16.5 - 19.4	9.0	0	2.0	2.0	5.0
19.5 - 22.4	7.0	0	2.0	1.0	3.0
22.5 - 25.4	0	0	0	0	0
25.5 - 28.4	0	0	0	0	0
28.5 - 31.4	0	0	0	0	0
31.5 - 34.4	0	0	0	0	0
34.5+	0	0	0	0	0
Slabs	0	0	0	0	0
Total	129.0	31.0	30.0	27.0	41.0

[1] Includes all dead and down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, at least 10 percent sound, and yardable.

Table 19--Average number of pieces per acre of usable logging residue by soundness and by diameter and length classes, Study Unit 1, Pansy Creek helicopter logging sale[1/] - Mt. Hood National Forest

Percent soundness and diameter class (inches)	Number of pieces all classes	Length class (feet)			
		4.0-7.9	8.0-13.9	14.0-20.9	21.0+
75+ percent sound:					
3.0 - 4.4	489.0	383.0	86.0	15.0	5.0
4.5 - 7.4	146.0	80.0	35.0	17.0	14.0
7.5 - 10.4	36.0	13.0	9.0	7.0	7.0
10.5 - 13.4	18.0	5.0	5.0	4.0	4.0
13.5 - 16.4	6.0	0	3.0	2.0	1.0
16.5 - 19.4	1.0	1.0	0	0	0
19.5 - 22.4	2.0	1.0	1.0	0	0
22.5 - 25.4	0	0	0	0	0
22.5 - 28.4	1.0	0	1.0	0	0
28.5 - 31.4	1.0	1.0	0	0	0
31.5 - 34.4	0	0	0	0	0
34.5+	0	0	0	0	0
Slabs	1.0	1.0	0	0	0
Total	701.0	485.0	140.0	45.0	31.0
50+ percent sound:					
3.0 - 4.4	525.0	417.0	88.0	15.0	5.0
4.5 - 7.4	157.0	88.0	37.0	18.0	14.0
7.5 - 10.4	38.0	14.0	10.0	7.0	7.0
10.5 - 13.4	20.0	6.0	5.0	4.0	5.0
13.5 - 16.4	7.0	0	4.0	2.0	1.0
16.5 - 19.4	3.0	1.0	1.0	0	1.0
19.5 - 22.4	5.0	2.0	2.0	1.0	0
22.5 - 25.4	0	0	0	0	0
25.5 - 28.4	1.0	0	1.0	0	0
28.5 - 31.4	2.0	1.0	0	1.0	0
31.5 - 34.4	0	0	0	0	0
34.5+	0	0	0	0	0
Slabs	1.0	1.0	0	0	0
Total	759.0	530.0	148.0	48.0	33.0
30+ percent sound:					
3.0 - 4.4	529.0	420.0	89.0	15.0	5.0
4.5 - 7.4	163.0	92.0	39.0	18.0	14.0
7.5 - 10.4	41.0	16.0	11.0	7.0	7.0
10.5 - 13.4	22.0	7.0	6.0	4.0	5.0
13.5 - 16.4	9.0	1.0	5.0	2.0	1.0
16.5 - 19.4	6.0	3.0	1.0	1.0	1.0
19.5 - 22.4	5.0	2.0	2.0	1.0	0
22.5 - 25.4	2.0	0	1.0	0	1.0
25.5 - 28.4	1.0	0	1.0	0	0
28.5 - 31.4	3.0	1.0	0	1.0	1.0
31.5 - 34.4	0	0	0	0	0
34.5+	1.0	0	0	0	1.0
Slabs	2.0	1.0	1.0	0	0
Total	784.0	543.0	156.0	49.0	36.0
10+ percent sound:					
3.0 - 4.4	537.0	426.0	90.0	16.0	5.0
4.5 - 7.4	169.0	95.0	41.0	19.0	14.0
7.5 - 10.4	45.0	18.0	13.0	7.0	7.0
10.5 - 13.4	25.0	9.0	6.0	5.0	5.0
13.5 - 16.4	13.0	3.0	6.0	3.0	1.0
16.5 - 19.4	8.0	4.0	2.0	1.0	1.0
19.5 - 22.4	6.0	2.0	2.0	1.0	1.0
22.5 - 25.4	3.0	1.0	1.0	0	1.0
25.5 - 28.4	2.0	0	1.0	0	1.0
28.5 - 31.4	4.0	1.0	1.0	1.0	1.0
31.5 - 34.4	0	0	0	0	0
34.5+	2.0	0	0	1.0	1.0
Slabs	2.0	1.0	1.0	0	0
Total	816.0	560.0	164.0	54.0	38.0

[1/] Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

Table 20--Average number of pieces per acre of usable logging residue by soundness and by diameter and length classes, Study Unit 2, Pansy Creek helicopter logging sale[1/] - Mt. Hood National Forest

Percent soundness and diameter class inches	Number of pieces all classes	Length class (feet)			
		4.0-7.9	8.0-13.9	14.0-20.9	21.0+
75+ percent sound:					
3.0 - 4.4	530.0	407.0	87.0	23.0	13.0
4.5 - 7.4	235.0	93.0	65.0	41.0	36.0
7.5 - 10.4	88.0	44.0	20.0	10.0	14.0
10.5 - 13.4	34.0	15.0	11.0	3.0	5.0
13.5 - 16.4	17.0	9.0	4.0	3.0	1.0
16.5 - 19.4	8.0	3.0	2.0	2.0	1.0
19.5 - 22.4	9.0	7.0	1.0	1.0	0
22.5 - 25.4	3.0	2.0	0	1.0	0
25.5 - 28.4	1.0	0	1.0	0	0
28.5 - 31.4	0	0	0	0	0
31.5 - 34.4	1.0	0	0	1.0	0
34.5+	2.0	2.0	0	0	0
Slabs	2.0	2.0	0	0	0
Total	930.0	584.0	191.0	85.0	70.0
50+ percent sound:					
3.0 - 4.4	536.0	412.0	88.0	23.0	13.0
4.5 - 7.4	241.0	98.0	65.0	42.0	36.0
7.5 - 10.4	92.0	45.0	22.0	10.0	15.0
10.5 - 13.4	41.0	17.0	14.0	4.0	6.0
13.5 - 16.4	24.0	12.0	7.0	3.0	2.0
16.5 - 19.4	9.0	3.0	3.0	2.0	1.0
19.5 - 22.4	12.0	9.0	1.0	1.0	1.0
22.5 - 25.4	5.0	3.0	0	1.0	1.0
25.5 - 28.4	1.0	0	1.0	0	0
28.5 - 31.4	0	0	0	0	0
31.5 - 34.4	1.0	0	0	1.0	0
34.5+	2.0	2.0	0	0	0
Slabs	2.0	2.0	0	0	0
Total	966.0	603.0	201.0	87.0	75.0
30+ percent sound:					
3.0 - 4.4	540.0	415.0	89.0	23.0	13.0
4.5 - 7.4	249.0	103.0	68.0	42.0	36.0
7.5 - 10.4	93.0	45.0	23.0	10.0	15.0
10.5 - 13.4	46.0	20.0	15.0	4.0	7.0
13.5 - 16.4	27.0	12.0	9.0	3.0	3.0
16.5 - 19.4	9.0	3.0	3.0	2.0	1.0
19.5 - 22.4	13.0	10.0	1.0	1.0	1.0
22.5 - 25.4	5.0	3.0	0	1.0	1.0
25.5 - 28.4	1.0	0	1.0	0	0
28.5 - 31.4	0	0	0	0	0
31.5 - 34.4	1.0	0	0	1.0	0
34.5+	2.0	2.0	0	0	0
Slabs	2.0	2.0	0	0	0
Total	988.0	615.0	209.0	87.0	77.0
10+ percent sound:					
3.0 - 4.4	546.0	418.0	92.0	23.0	13.0
4.5 - 7.4	254.0	105.0	68.0	44.0	37.0
7.5 - 10.4	102.0	50.0	25.0	12.0	15.0
10.5 - 13.4	47.0	20.0	15.0	5.0	7.0
13.5 - 16.4	33.0	12.0	14.0	4.0	3.0
16.5 - 19.4	10.0	3.0	3.0	3.0	1.0
19.5 - 22.4	15.0	12.0	1.0	1.0	1.0
22.5 - 25.4	7.0	5.0	0	1.0	1.0
25.5 - 28.4	1.0	0	1.0	0	0
28.5 - 31.4	0	0	0	0	0
31.5 - 34.4	1.0	0	0	1.0	0
34.5+	2.0	2.0	0	0	0
Slabs	2.0	2.0	0	0	0
Total	1,020.0	629.0	219.0	94.0	78.0

[1/] Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

Table 21--Average number of pieces per acre of usable logging residue by soundness and by diameter and length classes, Study Unit 3, Pansy Creek helicopter logging sale[1]--Mt. Hood National Forest

Percent soundness and diameter class (inches)	Number of pieces all classes	Length class (feet)			
		4.0-7.9	8.0-13.9	14.0-20.9	21.0+
75+ percent sound:					
3.0 - 4.4	501.0	415.0	73.0	8.0	5.0
4.5 - 7.4	315.0	242.0	38.0	19.0	16.0
7.5 - 10.4	167.0	102.0	30.0	17.0	18.0
10.5 - 13.4	61.0	27.0	21.0	7.0	6.0
13.5 - 16.4	32.0	18.0	7.0	5.0	2.0
16.5 - 19.4	11.0	6.0	3.0	1.0	1.0
19.5 - 22.4	3.0	2.0	1.0	0	0
22.5 - 25.4	5.0	5.0	0	0	0
25.5 - 28.4	2.0	1.0	1.0	0	0
28.5 - 31.4	1.0	1.0	0	0	0
31.5 - 34.4	0	0	0	0	0
34.5+	0	0	0	0	0
Slabs	6.0	6.0	0	0	0
Total	1,104.0	825.0	174.0	57.0	48.0
50+ percent sound:					
3.0 - 4.4	510.0	424.0	73.0	8.0	5.0
4.5 - 7.4	321.0	244.0	40.0	20.0	17.0
7.5 - 10.4	177.0	105.0	33.0	19.0	20.0
10.5 - 13.4	67.0	31.0	22.0	7.0	7.0
13.5 - 16.4	40.0	21.0	7.0	8.0	4.0
16.5 - 19.4	15.0	6.0	5.0	2.0	2.0
19.5 - 22.4	5.0	2.0	2.0	1.0	0
22.5 - 25.4	7.0	5.0	1.0	0	1.0
25.5 - 28.4	5.0	4.0	1.0	0	0
28.5 - 31.4	1.0	1.0	0	0	0
31.5 - 34.4	0	0	0	0	0
34.5+	0	0	0	0	0
Slabs	6.0	6.0	0	0	0
Total	1,154.0	849.0	184.0	65.0	56.0
30+ percent sound:					
3.0 - 4.4	510.0	424.0	73.0	8.0	5.0
4.5 - 7.4	323.0	246.0	40.0	20.0	17.0
7.5 - 10.4	181.0	105.0	35.0	20.0	21.0
10.5 - 13.4	71.0	32.0	23.0	8.0	8.0
13.5 - 16.4	43.0	23.0	8.0	8.0	4.0
16.5 - 19.4	22.0	9.0	7.0	3.0	3.0
19.5 - 22.4	6.0	2.0	3.0	1.0	0
22.5 - 25.4	8.0	5.0	1.0	1.0	1.0
25.5 - 28.4	5.0	4.0	1.0	0	0
28.5 - 31.4	1.0	1.0	0	0	0
31.5 - 34.4	0	0	0	0	0
34.5+	0	0	0	0	0
Slabs	6.0	6.0	0	0	0
Total	1,176.0	857.0	191.0	69.0	59.0
10+ percent sound:					
3.0 - 4.4	514.0	427.0	74.0	8.0	5.0
4.5 - 7.4	339.0	258.0	42.0	21.0	18.0
7.5 - 10.4	193.0	112.0	37.0	21.0	23.0
10.5 - 13.4	82.0	35.0	28.0	9.0	10.0
13.5 - 16.4	46.0	24.0	10.0	8.0	4.0
16.5 - 19.4	23.0	9.0	8.0	3.0	3.0
19.5 - 22.4	6.0	2.0	3.0	1.0	0
22.5 - 25.4	8.0	5.0	1.0	1.0	1.0
25.5 - 28.4	6.0	4.0	2.0	0	0
28.5 - 31.4	1.0	1.0	0	0	0
31.5 - 34.4	0	0	0	0	0
34.5+	0	0	0	0	0
Slabs	8.0	8.0	0	0	0
Total	1,226.0	885.0	205.0	72.0	64.0

[1] Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

Table 22--*Average gross and net volumes of usable logging residue by soundness and material handling class, Study Unit 1, Pansy Creek helicopter logging sale*[1]*-Mt. Hood National Forest*

Percent soundness and material handling class	Gross volume	Net volume	Soundness	Proportion of total
	- - -Cubic feet per acre- - -		- - -Percent- - -	
75+ percent sound:				
Felled and bucked	548.1	538.9	98.3	45.8
Felled and broken	609.6	600.1	98.4	51.0
Down and bucked	9.8	8.2	84.1	.8
Down and broken	28.0	23.0	82.2	2.3
Total	1,195.5	1,170.2	97.9	[2]99.9
50+ percent sound:				
Felled and bucked	817.4	692.3	84.7	46.3
Felled and broken	724.1	669.3	92.4	41.1
Down and bucked	25.8	19.4	75.3	1.5
Down and broken	196.6	122.4	62.2	11.1
Total	1,763.8	1,503.3	85.2	100.0
30+ percent sound:				
Felled and bucked	937.1	736.3	78.6	44.4
Felled and broken	746.7	677.3	90.7	35.4
Down and bucked	76.0	36.2	47.6	3.6
Down and broken	352.1	177.2	50.3	16.7
Total	2,111.9	1,626.9	77.0	[2]100.1
10+ percent sound:				
Felled and bucked	961.4	736.9	76.7	37.0
Felled and broken	764.9	680.9	89.0	29.4
Down and bucked	99.8	40.5	40.5	3.8
Down and broken	772.2	236.0	30.6	29.7
Total	2,598.3	1,694.3	65.2	[2]99.9

[1]Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

[2]Total does not equal 100 because of rounding.

Table 23--*Average gross and net volumes of usable logging residue by soundness and material handling class, Study Unit 2, Pansy Creek helicopter logging sale*[1]*- Mt. Hood National Forest*

Percent soundness and material handling class	Gross volume	Net volume	Soundness	Proportion of total
	- - -Cubic feet per acre- - -		- - -Percent- - -	
75+ percent sound:				
Felled and bucked	1,233.5	1,202.6	97.5	54.1
Felled and broken	819.4	803.5	98.1	36.0
Down and bucked	57.9	48.0	82.9	2.5
Down and broken	167.3	142.1	84.9	7.3
Total	2,278.1	2,196.1	96.4	[2]99.9
50+ percent sound:				
Felled and bucked	1,358.7	1,281.5	94.3	50.5
Felled and broken	838.3	814.6	97.2	31.2
Down and bucked	122.8	89.3	72.8	4.6
Down and broken	370.9	262.9	70.9	13.8
Total	2,690.6	2,448.2	91.0	[2]100.1
30+ percent sound:				
Felled and bucked	1,389.2	1,292.9	93.1	47.9
Felled and broken	918.2	839.5	91.4	31.6
Down and bucked	167.6	102.9	61.4	5.8
Down and broken	428.0	282.8	66.1	14.7
Total	2,903.0	2,518.1	86.7	100.0
10+ percent sound:				
Felled and bucked	1,401.1	1,294.1	92.4	44.6
Felled and broken	943.6	842.0	89.2	30.1
Down and bucked	195.9	107.5	54.9	6.2
Down and broken	598.9	302.8	50.6	19.1
Total	3,139.5	2,546.3	81.1	100.0

[1] Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

[2] Total does not equal 100 because of rounding.

Table 24--*Average gross and net volumes of usable logging residue by soundness and material handling class, Study Unit 3, Pansy Creek helicopter logging sale*[1]*- Mt. Hood National Forest*

Percent soundness and material handling class	Gross volume	Net volume	Soundness	Proportion of total
	- - -Cubic feet per acre- - -		- - -Percent- - -	
75+ percent sound:				
Felled and bucked	1,591.8	1,571.9	98.8	57.5
Felled and broken	827.6	821.3	99.2	29.9
Down and bucked	111.6	95.5	85.6	4.0
Down and broken	236.4	207.7	87.9	8.5
Total	2,767.4	2,696.4	97.4	[2]99.9
50+ percent sound:				
Felled and bucked	1,809.2	1,693.4	93.6	54.5
Felled and broken	913.5	869.3	95.2	27.5
Down and bucked	181.8	139.4	76.7	5.5
Down and broken	413.1	311.0	75.3	12.5
Total	3,317.6	3,013.2	90.8	100.0
30+ percent sound:				
Felled and bucked	1,866.6	1,714.7	91.9	51.9
Felled and broken	984.0	896.2	91.1	27.4
Down and bucked	222.9	154.4	69.3	6.2
Down and broken	523.1	350.8	67.1	14.5
Total	3,596.7	3,116.0	86.6	100.0
10+ percent sound:				
Felled and bucked	1,866.6	1,714.7	91.9	47.7
Felled and broken	1,022.3	903.5	88.4	26.1
Down and bucked	261.7	158.7	60.7	6.7
Down and broken	765.5	384.1	50.2	19.5
Total	3,916.0	3,161.0	80.7	100.0

[1] Includes all down material averaging at least 3.0 inches in diameter (inside bark) and 4.0 feet long, and yardable.

[2] Total does not equal 100 because of rounding.

CONCLUDING REMARKS

Since results of the present investigation are based on only a case study of one particular helicopter logging operation, inferences drawn from these results may not necessarily be applicable to other operations logged in the same manner. The information presented, however, can still be used by forest managers in evaluating residue production, its reduction, characteristics, volumes, and potential uses. Some indication of the fuel loading that can be expected from similar harvesting operations is also made available. Furthermore, a basis is provided with which to evaluate the effects of change in utilization either from changes in the market or in contractural requirements such as required yarding of unutilized material (YUM). Results of this study are summarized in table 2.

Our data indicate YUM yarding substantially reduced the coarse residue volumes in the study units. Contractual specifications for yarding unutilized materials influenced the volume and piece-count distribution of the usable residues remaining on the site. Study results tend to suggest YUM yarding was less effective in a partial cut than in a clearcut.

Even with YUM yarding, we found a substantial volume of residues (usable and unusable) (table 2) still remaining on the logging sites. Our results suggest that these residues, because of their size and character, will continue to be a problem regardless of whether or not the logging operation calls for the yarding of unutilized materials.

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CONVERSION FACTORS

1 inch = 2.54 centimeters
1 foot = 0.304 8 meter
1 acre = 0.404 686 2 hectare
1 cubic foot acre = 0.069 972 5 cubic meter/hectare

1 pound (lb) = 0.453 6 kilogram
1 ton = 2,000 lbs = 907.2 kilograms
1 bone-dry unit of chips (BDU) = 2,400 pounds

Specific density (oven-dry weight/green volume)
(Hartman [1976] table E-1)
Coast Douglas-fir = 28.0 pounds per cubic foot
Western hemlock = 26.2 pounds per cubic foot

1 cubic foot Douglas-fir = 0.011 666 6 BDU chips
1 cubic foot western hemlock = 0.010 916 6 BDU chips

1 cubic foot Douglas-fir = 249,000 Btu per cubic foot
(Hartman [1976] table G-1)
1 cubic foot western hemlock = 204,000 Btu per cubic foot

GPO 986-816

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The FOREST SERVICE of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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